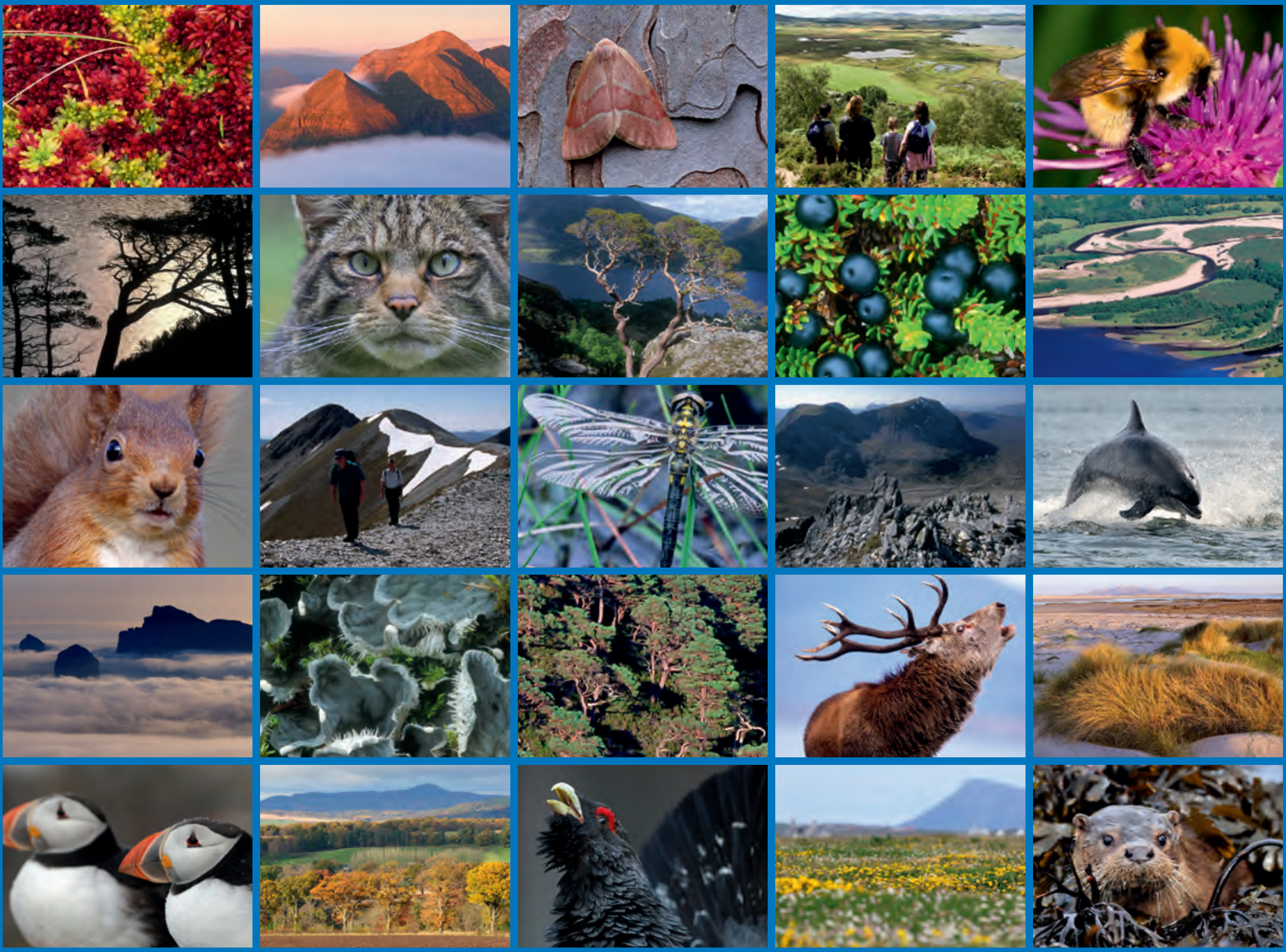
Scottish Natural Heritage
Commissioned Report No. 783

Understanding the potential effects of wave energy devices on kelp biotopes



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COMMISSIONED REPORT

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Understanding the potential effects of wave energy devices on kelp biotopes

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This report should be quoted as:

MacLeod, A.K., Orr, K.K., Greenhill, L., & Burrows, M. 2014. Understanding the potential effects of wave energy devices on kelp biotopes. *Scottish Natural Heritage Commissioned Report No. 783.*

COMMISSIONED REPORT

Summary

Understanding the potential effects of wave energy devices on kelp biotopes

Commissioned Report No. 783
Project no: 14565
Contractor: SRSL
Year of publication: 2014

Keywords

Marine renewables; wave energy converters; kelp; risk assessment; best practice.

Background

Scottish Natural Heritage (SNH) has identified a research need to improve understanding of the changes to kelp habitats as a result of the development of wave energy projects around Scotland. Notable development is planned in The Crown Estate's current leasing round with further zones being identified by Scottish Government in the latest draft plan options for the sector. Some of these developments have the potential to occur within the subtidal zone, where kelp habitats are prevalent.

Activities associated with wave projects such as installation, operation, maintenance and decommissioning may impact kelp communities in a number of ways, including kelp removal to permit installation of devices and associated infrastructure (cables and pipelines).

Main findings

- Areas designated for the deployment of shallow-water and shore-based wave energy converters (WECs) in Scotland coincide with important kelp habitats (dominated by *Laminaria hyperborea*).
- Kelp covers approximately 3600 km^2 of Scotland's coast and the estimated 10 million tonnes of kelp biomass supports more than 1800 different species of flora and fauna including other seaweeds, invertebrates, fish, diving birds and otters.
- Existing wave lease areas coincide with 1.2% of Scotland's kelp habitats where kelp has a 50% likelihood of being rare or more abundant on the SACFOR scale.
- The expected area of impact on kelp habitats will be much lower, given that the footprint of individual WECs will be far smaller than the wave lease areas.
- Environmental impacts associated with wave energy projects may occur during construction, operation, maintenance and decommissioning project phases. Activities with potential impacts on kelp include: site preparation; installation of mooring anchors, cabling, mono-piling and / or construction of breakwaters; introduction of new substrates such as rock mattressing, metal or plastic piping; routine maintenance and decommissioning. These activities may result in direct loss of kelp habitats and / or temporary disturbances from which kelp can recover.
- WECs may indirectly impact kelp habitats and wider nearshore ecosystems by inducing changes in hydrodynamics, sedimentation and wave energy, which favour the

establishment of less diverse seaweed communities. The introduction of non-native species also poses a risk to kelp communities. However, the degree of this threat is largely uncertain.

- Kelp habitats are subject to a high level of natural disturbance (for example loss of biomass during storms) and have an inherent capacity to recover rapidly.
- After clearing, the kelp canopy can return to virgin biomass within 2-5 years and associated flora and fauna may take 1 to >6 years to return to their original density, dependent on species. Kelps are also able to colonise a variety of artificial substrates such as concrete blocks and rock mattressing. Repeat clearing of kelp at intervals of less than 2 years will prevent recovery of kelp habitat.
- Recovery of kelp habitats after disturbance can be facilitated by:
    - Introducing new substrates that best match the natural environment.
    - Not sterilising new surfaces unless essential for device operation.
    - Leaving kelp holdfasts intact when clearing and thereby retaining refuges for associated fauna.
    - Allowing kelp canopy to mature (>5 years age) between successive clearings.
    - Avoiding sites that are adjacent to extensive areas of fine sediments.
- The findings of the objective risk assessment are that kelp habitats have a medium to very high sensitivity to site-specific disturbances that may be induced by wave energy projects. However, given the extent of kelp habitat in Scotland and the level of natural disturbance tolerated by these habitats, the magnitude of the predicted impact is generally minor or negligible on a regional and national scale.

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1. INTRODUCTION

Marine renewable energy is a rapidly growing sector in Scotland, with strong political support accompanying the drive towards a low carbon economy. This includes the well-publicised target of meeting an equivalent of 100% of Scotland's gross annual electricity consumption from renewable energy by 2020. Scotland has an estimated 25% of Europe's offshore wind and tidal resource and 10% of the wave resource (Scottish Government, 2013) and the deployment of marine renewable energy devices is set to increase significantly in coming years.

Figure 1 indicates the scale of The Crown Estate's current leased areas for wave developments, in addition to wave draft locational plan options, identified by Marine Scotland, in Scottish waters. As a more established industry, offshore wind represents a large proportion of the current and foreseeable installed generation capacity. Present wave and tidal energy development is at an earlier stage, with test devices and small grid connected projects comprising a fraction of overall renewable energy capacity.

The wave energy sector is the least developed of the offshore renewable energy sectors with projects not yet approaching full scale commercial deployment. The Crown Estate has granted a number of leases for wave energy developments across the Pentland Firth and Orkney Waters, Shetland and the Western Isles amounting to approximately 660MW of capacity. Projects are in various stages of planning and development and rely on a number of critical aspects, such as transmission infrastructure and technological capability, however, growth in the sector is anticipated. The Draft Sectoral Marine Plan for Offshore Wind, Wave and Tidal Energy identifies further areas for potential development of commercial scale wave energy projects (defined as over 30MW by Marine Scotland) which will be taken forward to the leasing stage (depending on the outcomes of the consultation process) (Scottish Government, 2013). The development of the wave energy industry in areas of high wave energy may coincide with areas known to support important kelp habitats (Smale et al., 2013).

All capacity is subject to the obtaining of marine licences and associated consents from the relevant authority, including satisfying all legislative requirements relating to the environment and nature conservation. To enable the sector to progress, it is therefore necessary to consider the risks to environmental features and work is progressing at a strategic level and through project-specific investigations to understand possible effects. This report presents the results of an investigation to understand the specific issue of effects of wave energy development on kelp habitats.

Potential impacts to kelp habitats may occur during construction, operation, maintenance and decommissioning of wave energy projects. Key effects during the installation of foundations and transmission infrastructure include: 1) habitat loss through the alteration of the existing seabed to enable placement; and 2) disturbance due to removal of kelp biomass as a result of a number of construction and maintenance activities. During device operation, changes in associated marine communities may be caused by alteration of the physical environment, such as changes in sediment dynamics and hydrography, and the creation of artificial habitats (Inger et al., 2009). Maintenance activities may require the repeat removal of kelp and associated species from the existing infrastructure for inspection and maintenance. Possible effects during decommissioning are comparable with the construction phase, i.e. habitat loss and disturbance, as well as the potential for activities releasing pollutants which may affect associated communities.

This report assesses in detail the likely interactions between kelp habitats and activities associated with the developing wave energy industry. Using key features of each device, it is possible to group different approaches to extracting wave energy in order to evaluate which features are likely to cause changes in kelp communities and their ‘functioning’. A review of the ecological implications of kelp community disturbance will allow for such changes to kelp communities to be detailed in context with natural processes of succession and disturbance. Such information will aid the wave energy community (developers, regulators, etc.) to more accurately determine their impact on kelp communities whilst identifying opportunities for mitigation and best practice.

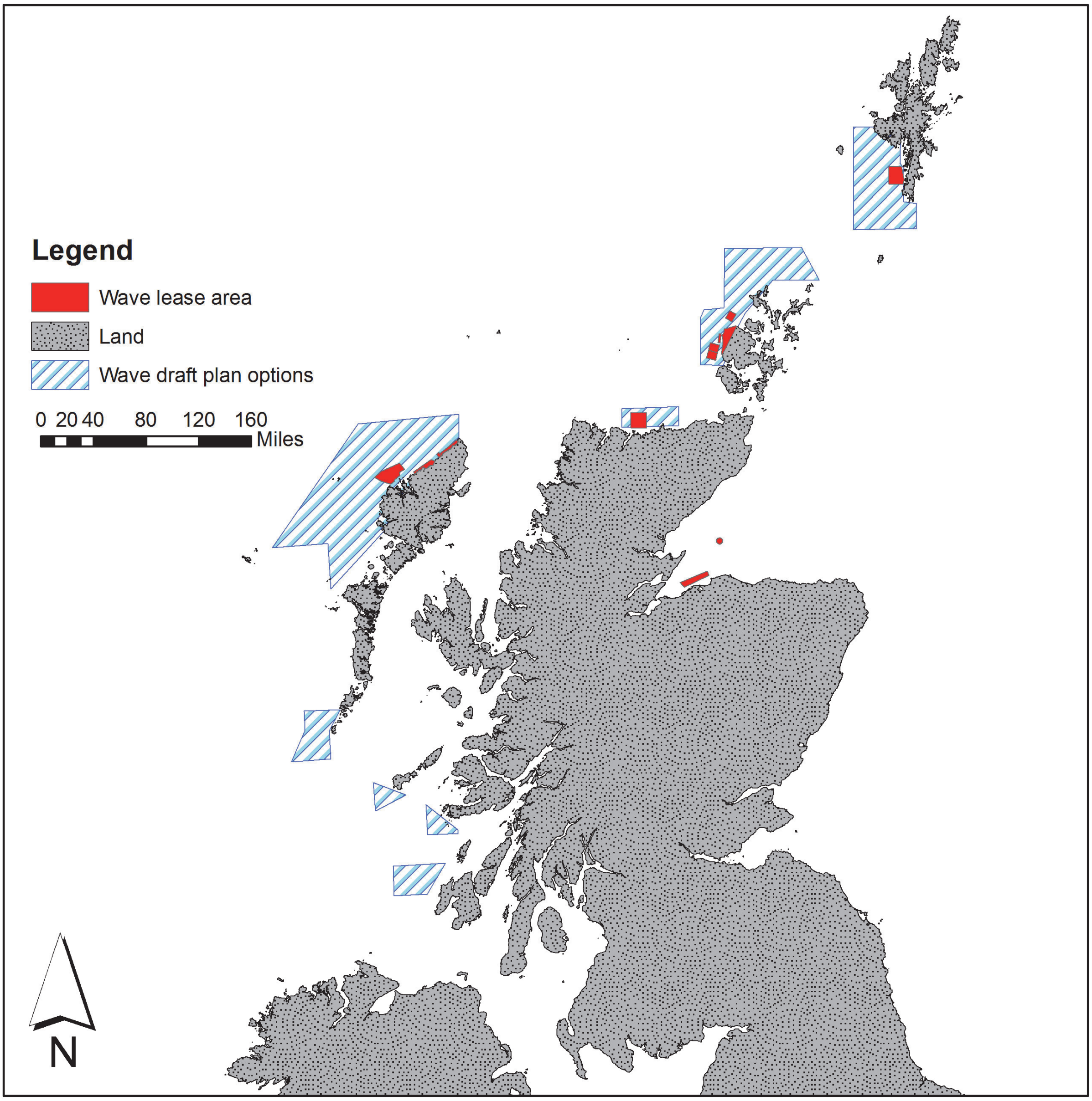

Figure 1:* *Leased areas for wave energy projects in Scotland (red). *Wave draft locational plan options have also been shown (blue). This figure has been produced from data supplied by the Scottish Government.*

2. REVIEW OF KELP HABITATS AND THEIR PROTECTION

2.1 General introduction

Kelps are large brown seaweeds that dominate temperate coastlines and are among the most productive ecosystems on earth (Steneck et al., 2002, Smale et al., 2013). In Scotland, kelps are particularly abundant on the wave-exposed west and north coasts (Walker, 1954) and occur on rocky substrates from the lower shore to depths of ~20 – 30 m (Connor et al., 2005). Kelps grow several metres high, depending on species (up to 3.5 m canopy height in UK waters) and are composed of a holdfast that anchors the kelp to rocks, an upright stalk (stipe) and leaf-like fronds that are attached to the stipe (Birkett et al., 1998) (Figure 2). Several different kelp species may co-exist within a canopy, however, the most dominant subtidal kelp in most of the UK's wave-exposed waters is *Laminaria hyperborea*, a long-lived climax species with a lifespan of 5 -18 years (Smale et al., 2013).

Kelp plants act as three-dimensional 'ecosystem engineers', forming forests and modifying the local environment for other organisms by altering local light conditions, water flow and sedimentation rates (Smale et al., 2013). More than 1800 different species have been recorded within kelp-dominated habitats in the UK (Birkett et al., 1998). Epiphytes attach directly to the stipe, and to a lesser extent the fronds and provide a secondary habitat used by many other invertebrates (Christie et al., 2003). The kelp holdfast supports the most diverse assemblage of fauna, harbouring around 30 -70 different species (Christie et al., 2003, Moore, 1973b, Moore, 1973a, Moore, 1974). Rich assemblages of foliose red seaweed and 'cushion fauna' (e.g. anemones and sponges) grow on the rocks beneath the kelp canopy (Birkett et al., 1998). In the UK and Ireland larger invertebrates (>5 cm) such as sea urchins (Jones and Kain, 1967) and European lobster (Jones and Kain, 1967) live amongst the kelp, the latter being commercially important (Smale et al., 2013). Kelp forests are used as feeding areas and nursery grounds by NE Atlantic fish species such as Atlantic cod, pollack and wrasse (Smale et al., 2013, Norderhaug et al., 2005). The invertebrate and fish life attracts larger predators such as diving birds, otters and seals (Smale et al., 2013). The number of other species present in the infralittoral zone increases with the cover of *L. hyperborea*, which is considered to be the main driver of biodiversity on sublittoral rock in UK waters (Burrows, 2012).

The total biomass of subtidal kelp (*Laminaria spp.*) around Scotland is estimated to be 10 million tons which grows with considerable variation in density and biomass over a sublittoral area of 8000 km^2 (Walker, 1954). It is important to note that the probability of finding kelp varies within this 8000 km^2 of rocky sublittoral habitat, depending on environmental factors and that kelp is not abundant within this entire area. This early study by Walker (1954) found that 39% of Scotland's kelp biomass (total approximately 10 million tons) only covered 1115 km^2 of seabed (Walker, 1954) therefore, by extrapolation, 100% of Scotland's abundant kelp resources are expected to cover 2860 km^2 of Scotland's seabed. Recent models were created to better predict the extent of kelp habitat in Scotland which take into account bathymetry, depth, wave fetch, and chlorophyll-*a* concentrations (Burrows et al., in press). In order to produce digital maps, a statistical (ordinal logistic regression) model was fitted to abundance data for kelp generated from the Marine Nature Conservation Review (Burrows et al., in press). The modelling results found that within 6000 km^2 of sublittoral seabed shallower than 50 m there is a 25% chance of finding kelp at an abundance scale of rare or more (SACFOR scale: Superabundant [S >80%], Abundant [A 40-79%], Common [C 20-39%], Frequent [F 10-19%], Occasional [O 5-9%], Rare [R 1-5%] (Connor et al., 2003). Similarly, there is a 50% chance of finding kelp within a 3600 km^2 area of seabed (Burrows et al., in press). Applying more concise boundaries to the model, the area of seabed where there was a 50% chance that kelp was predicted to be abundant or more was 2155 km^2 (Burrows et al., in press). The latter two predictions are generally in line (approximately +/-25%) with early estimates made by Walker (1954), suggesting that the majority of Scotland's kelp forests occurs within an area of 2155 to 3600 km^2. This report defines the typical extent of kelp to be approximately 3600 km^2. It is considered that this estimate is useful in the context of this work as it includes all abundance scales for kelp.

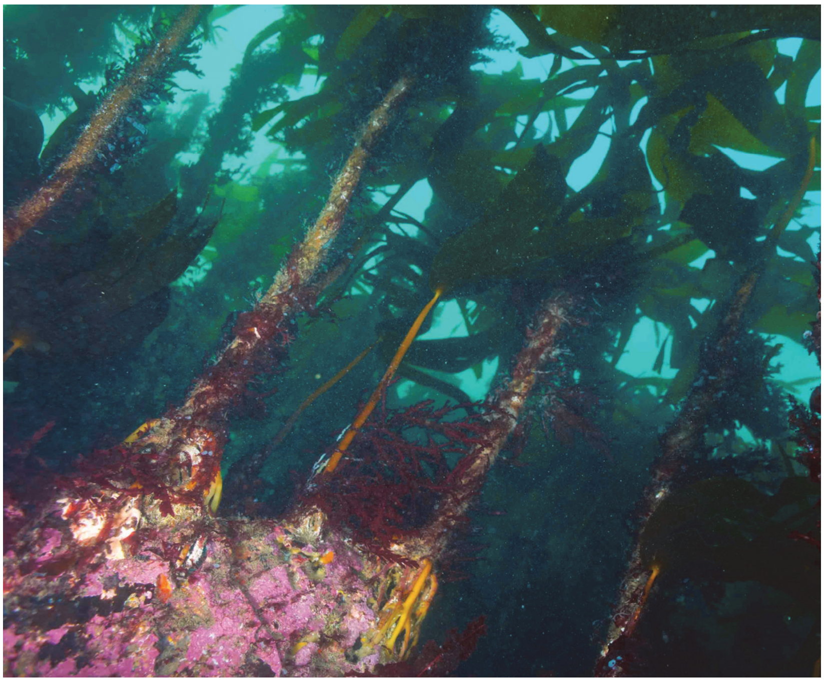

Figure 2: A kelp forest on the west coast of Scotland. Photo courtesy of Hugh Brown from the National Facility for Scientific Diving (Scottish Association for Marine Science).

2.2 Data available for kelp habitats in the UK

The ecology of kelp forests has been understudied in the UK relative to other areas of the world (Smale et al., 2013) and the regional impacts of removing or harvesting kelp are largely unknown. The Marine Nature Conservation Review (MNCR) which was undertaken by the Joint Nature Conservation Committee (JNCC) provides the most comprehensive baseline information on kelp habitats within UK waters (Connor et al., 2005). This dataset focuses on benthic habitats and their associated communities (Connor et al., 2005) and the MNCR also produced the ‘Marine Habitat Classification for Britain and Ireland’ in which biotopes are classified and coded according to their physical environment (habitat) and assemblages of conspicuous species. This is one of the most comprehensive marine benthic classification systems currently in use and is referred to substantially in this report.

Much less information is available on the non-benthic species and higher trophic level fauna such as fish, diving birds and mammals and their role within kelp-dominated habitats. Throughout the following review, the emphasis has been on data available on kelp ecosystems in Scotland, but references have also been made to relevant research in other areas in the north-east Atlantic, for example Norwegian kelp forests.

2.3 Wave exposed kelp biotopes in the UK

With regards to the deployment of wave energy devices, the most direct ecological impacts will likely occur within habitats subject to exposed or extremely exposed wave action. These habitats support the biotope known as ‘kelp with cushion fauna and/or foliose red seaweed’ (biotope code: IR.HIR.KFaR), as defined by the MNCR (Connor et al., 2005). The main kelp species within this biotope is *Laminaria hyperborea* (Connor et al., 2005, Burrows, 2012), which extends from extreme low water to ~8 m in turbid coastal waters and to ~30m in clear waters, as found off the Western Isles (Tayler-Walters, 2007). The dominant flora and fauna that characterise high energy kelp biotopes (IR.HIR.KFaR) are given in Table 1.

Within high energy kelp biotopes (IR.HIR.KFaR) there are a number of ‘biotope complexes’ which are defined according to their depth, wave exposure and species assemblages. On the extreme lower shore in the very shallow subtidal (sublittoral fringe) there is usually a narrow band of dabberlock kelp, *Alaria esculenta* (KFaR.Ala, Figure 3 A), which extends to 5 or 10 m depth in areas of very strong wave action (Connor et al., 2005). Mussels, *Mytilus edulis*, co-occur with *A. esculenta* in very wave-exposed environments and some oarweed, *Laminaria digitata* may be present in less exposed conditions. Below the band of *A. esculenta*, dense forests of *L. hyperborea* are present (KFaR.LhypFa, Figure 3 B) in shallow exposed conditions. In these wave-surged environments, the kelp forests co-occur with the greatest diversity of other seaweeds and invertebrates such as red foliose seaweeds, coralline algae, soft coral, anthozoans, sponges, crabs, starfish, urchins, hydroids and bryozoans. As the force of wave surge decreases with depth, the density of associated fauna decreases and the kelp forest becomes dominated by *L. hyperborea* and dense red seaweeds (LhypR, Figure 3 C). Below the limit of kelp, dense turf and foliose red seaweeds occur (Connor et al., 2005).

In areas with unstable bedrock such as boulders and pebbles that are shifted during storms, the long-lived *L. hyperborea* cannot become well-established. These unstable benthic environments are instead dominated by the fast-growing, opportunistic kelps *Laminaria saccharina* and/or *Saccorhiza polyschides* (KSed.Sac and KSed.LsacSac, Figure 3 D), and species diversity and richness is generally low in comparison to the more stable *L. hyperborea* communities (Connor et al., 2005). All biotope complexes that occur in kelp-dominated wave-exposed environments are described in Annex 1 and 2.

Figure 3: Kelp habitats found within areas of exposed infralittoral rock, and listed as 'important biotopes' under the EC Habitats Directive (Photo credit: MarLIN http://www.marlin.ac.uk).

Table 1: Species that characterise extremely wave-exposed infralittoral habitats with kelp and cushion fauna and/or red seaweeds (biotope code: IR.HIR.KFaR).

Phylum	Species	Common name	Abundance (SACFOR)
Fauna			
Cnidaria	*Alcyonium digitatum*	Dead man's fingers	Occasional
Cnidaria	*Urticina felina*	Dahlia anemone	Occasional
Cnidaria	*Sagartia elegans*	A sea anemone	Occasional
Cnidaria	*Corynactis viridis*	Jewel anemone	Frequent
Annelida	*Pomatoceros triqueter*	Tubeworm	Occasional
Mollusca	*Calliostoma zizyphinum*	Painted top shell	Occasional
Echinodermata	*Asterias rubens*	Common starfish	Occasional
Echinodermata	*Echinus esculentus*	Edible sea urchin	Occasional
Chordata	*Botryllus schlosseri*	Star ascidian	Occasional
Red seaweeds			
Rhodophyta	*Callophyllis laciniata*	Red seaweed	Occasional
Rhodophyta	*Corallinaceae*	Corraline red algae	Common
Rhodophyta	*Corallina officinalis*	Coral weed	Frequent
Rhodophyta	*Plocamium cartilagineum*	Red seaweed	Frequent
Rhodophyta	*Cryptopleura ramosa*	Red seaweed	Frequent
Rhodophyta	*Delesseria sanguinea*	Sea Beech	Frequent
Brown seaweeds			
Ochrophyta	*Dictyota dichotoma*	Brown algae	Frequent
Ochrophyta	*Laminaria hyperborea*	Tangle or Cuvie	Common
Ochrophyta	*Alaria esculenta*	Dabberlocks	Common

2.4 Protection of kelp habitat

Many species and habitats have been identified previously in European Community Directives, domestic legislation, Biodiversity Action Plans, as well as the OSPAR list of threatened or declining habitats and species. Of these, kelp habitats found in high-energy environments are listed as Annex I habitats of the Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora (the Habitats Directive (Council Directive 92/43/EEC, 1992)).

With respect to potential impacts from wave energy generation, kelp habitats listed as Annex I habitats under the Habitats Directive include: *Alaria esculenta* on exposed sublittoral fringe bedrock (IR.HIR.KFaR.Ala), *Laminaria hyperborea* with dense foliose red seaweeds on exposed infralittoral rock (IR.EIR.KFaR.LhypR), *Laminaria saccharina* and/or *Saccorhiza polyschides* on exposed infralittoral rock (IR.EIR.KFaR.LsacSac), *Laminaria hyperborea* forest with a faunal cushion (sponges and polyclinids) and foliose red seaweeds on very exposed upper infralittoral rock (IR.HIR.KFaR.LhypFa) (Figure 3) (Howson et al., 2012). None of the individual species that characterise kelp biotopes within high energy, infralittoral rocky habitats (IR.HIR.KFaR, Table 1) are protected under specific legislation (e.g. under the Bern Convention, EC Habitats Directive, CITES, Wildlife and Countryside Act, UK Biodiversity Action Plan Species, OSPAR Priority List, or the Nationally Rare or Scare Species list).

Member States are required to maintain or restore European protected habitats and species listed in the Annexes of the Habitat Directive at Favourable Conservation Status (FCS). FCS, relative to habitats, is defined in Article 1 of the Directive as follows:

"Conservation status of a species means the sum of the influences acting on a natural habitat and its typical species that may affect its long-term survival of its typical species within the territory referred to in Article 2 (Council Directive 92/43/EEC, 1992). The conservation status will be taken as 'favourable' when:

- its natural range and areas it covers within that range are stable or increasing, and
- the specific structure and functions which are necessary for its long-term maintenance exist and are likely to continue to exist for the foreseeable future, and
- the conservation status of its typical species is favourable"

Member States are required (by Article 17 of the Directive) to report on implementation of the Habitats Directive every six years, including FCS for habitats and species. This is undertaken at bio-geographical level, which for the UK is the Atlantic Region.

The Marine Nature Conservation Strategy in Scotland sets out to protect a subset of habitats and species upon which to focus conservation efforts. These habitats and species are known as Priority Marine Features (PMFs) and provide a focus for marine conservation activities through Marine Scotland's 'three-pillar approach' to effective marine nature conservation (Scottish Government, 2011). This approach includes species conservation measures, site protection measures and wider seas policies and measures (Scottish Government, 2011). As part of this approach, Marine Scotland aims to ensure that populations of PMFs receive appropriate protection and conservation measures (Scottish Government, 2011). However, of the kelp habitats present in Scotland's high energy coastlines none were listed as PMFs (Howson et al., 2012).

The framework of conservation legislation is complex, with a more recent development towards more holistic ecosystem-based approaches requiring a broader view than species-specific management. However, alongside the development of more integrated management frameworks (e.g. under the Marine Strategy Framework Directive) it is appropriate to account for specific legislation relating to kelp habitats to meet statutory requirements.

In summary, kelp biotopes are protected by conservation legislation, as defined through the Marine Nature Conservation Strategy and as listed on Annex I of the Habitats Directive and specific statutory requirements therefore apply. However, it is necessary to approach the assessment of effects on a holistic basis, to support the drive towards more integrated ecosystem-based management of the marine environment

3. REVIEW OF WAVE ENERGY TECHNOLOGIES

Wave energy technologies encompass a wide range of methods to convert kinetic energy contained in passing waves to electrical energy. This section summarises different types of Wave Energy Convertors (WECs) and explores the principal activities associated with wave energy projects that may impact kelp communities. Environmental impacts associated with wave energy projects such as habitat loss and/or disturbance created through kelp removal are strongly dependent on factors such as the depth, timing, frequency and extent of disturbance.

Technologies can be largely grouped by the environment in which they are deployed (open-water, seabed mounted and shore-based devices) and the method each device uses to produce energy. Many WECs are deployed in open water (>50m water depth) using a range of mooring systems. Examples of open water devices include, but are not limited to, attenuator, bulge wave and rotating mass devices (Figure 4). Seabed mounted WECs use a range of methods to securely fix structures to the seabed. Due to the methods used to convert kinetic energy to electrical energy, such devices tend to be deployed in shallower near shore locations (Aquatera, 2013). These include point absorbers, oscillating wave surge converters and submerged pressure differential devices (Figure 5). Shore-based WECs require the modification of the shore in some way to house different technologies. Shore-based WECs can be fixed to existing infrastructure, such as harbour breakwaters or built directly into the shore requiring varying degrees of habitat modification. Examples of these technologies include the oscillating water column and overtopping devices (Figure 6).

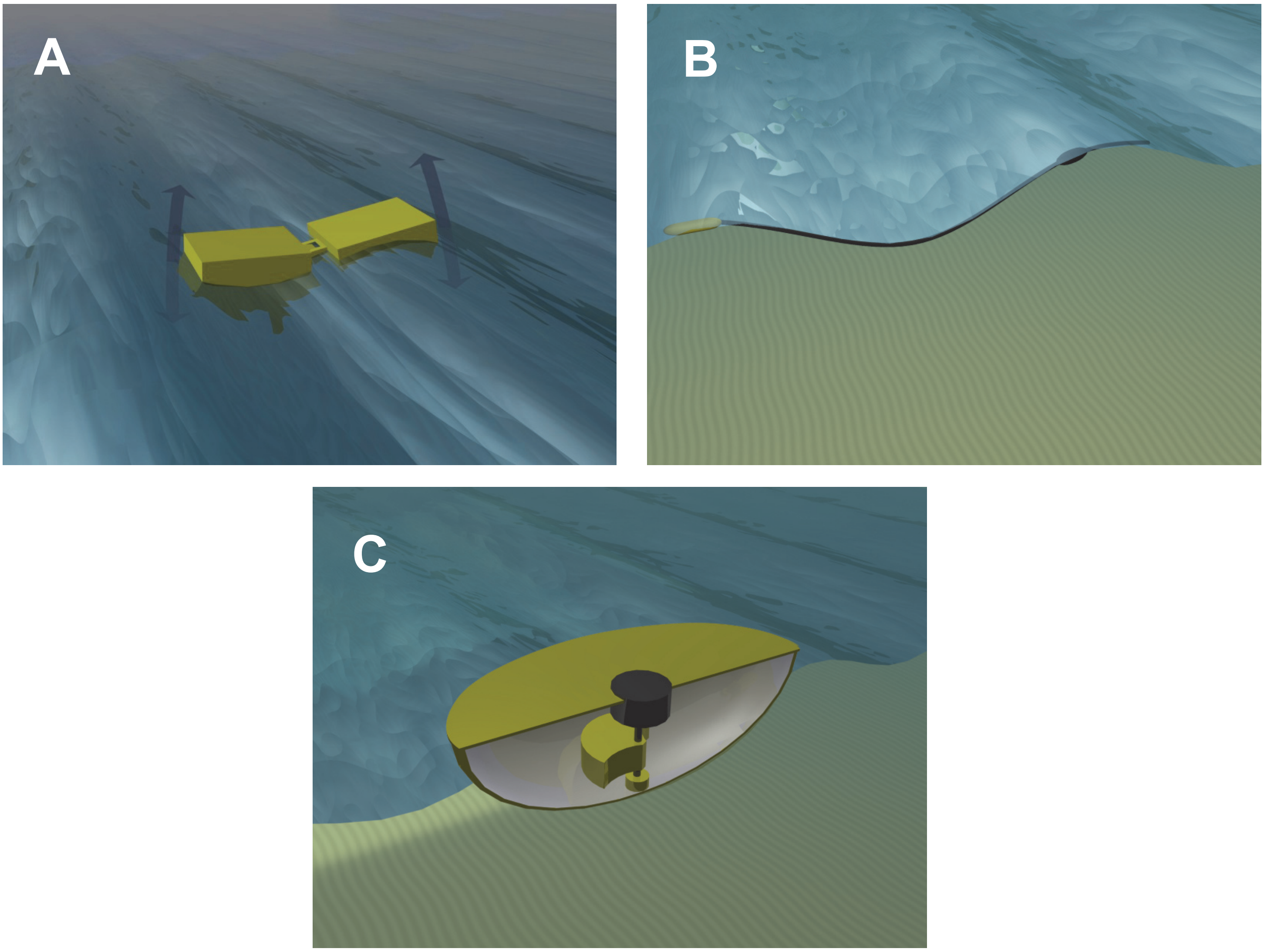

Figure 4: Examples of moored Wave Energy Converters. A) *Attenuator: this device operates parallel to the wave direction and captures energy as different sections move relative to one another.* ***B)*** *Bulge wave: this flexible tube fills with water and produces a pressure differential (bulge) which is enhanced to drive a turbine located at the stern.* ***C)*** *Rotating mass: this device captures the heaving and swaying in waves that rotates a weight fixed to an electric generator. Images created by Aqua-RET.*

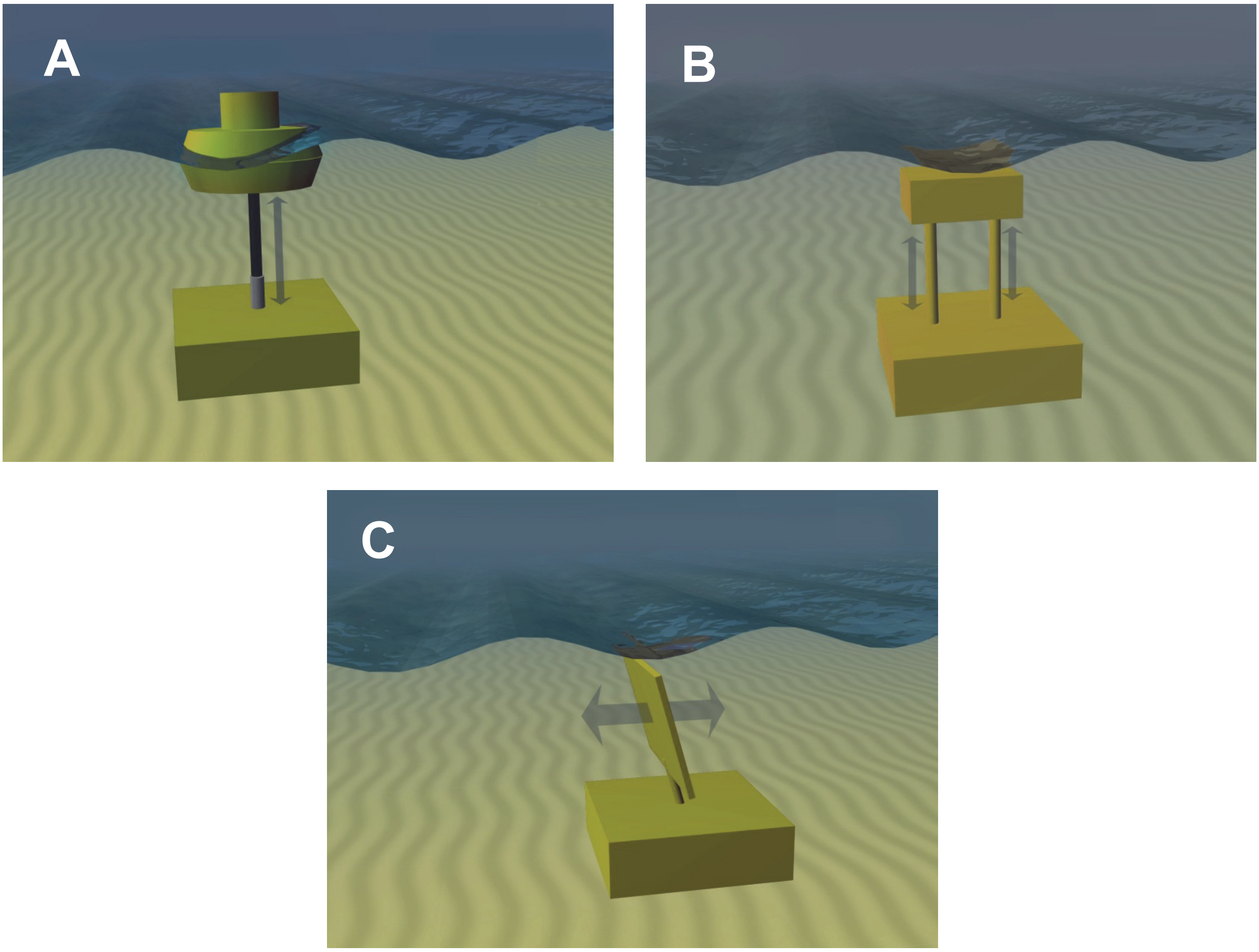

Figure 5: Examples of seabed mounted Wave Energy Converters. A) *Point absorber: this device uses a floating structure that captures energy from all directions as the float moves relative to the base.* ***B)*** *Submerged pressure differential: uses a submerged float that moves relative to the rest of the structure as a result of a pressure differential.* ***C)*** *Oscillating wave surge converter: this device captures energy from wave surges as the arm is forced to move on a hinge relative to the rest of the structure. Images created by Aqua-RET.*

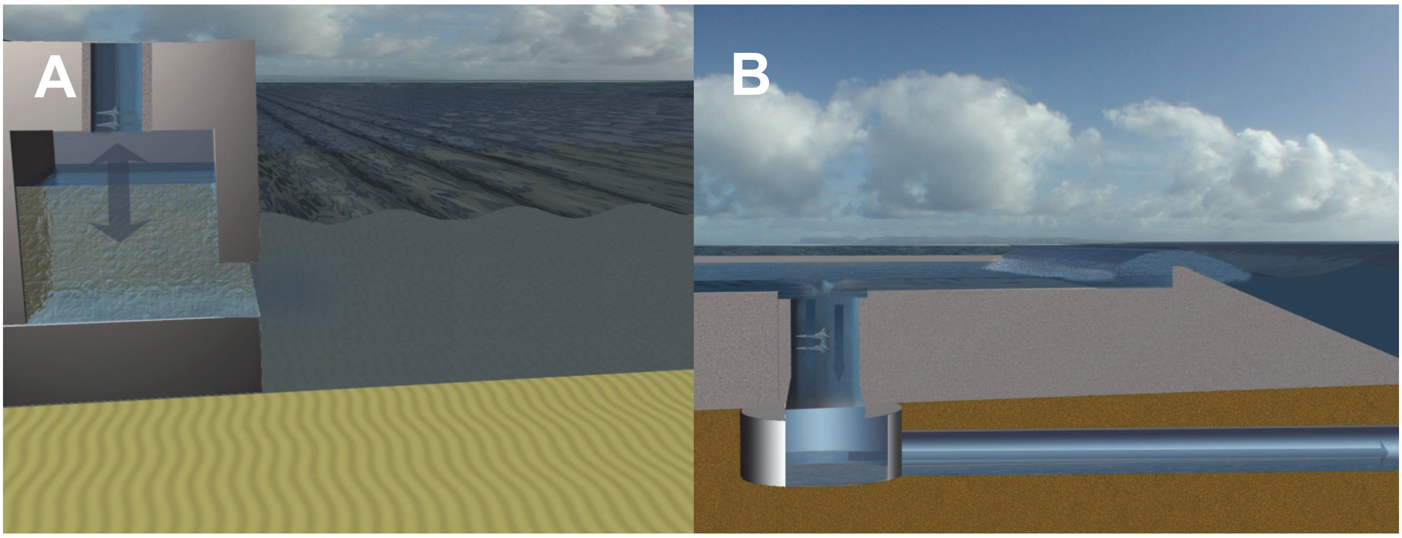

Figure 6: Examples of shore-based Wave Energy Converters. A) *Oscillating water column: this device uses a partially submerged hollow structure. This captures energy by driving a turbine that turns as a result of changes in pressure as water rises and falls inside.* ***B)*** *Overtopping device: uses the potential energy created by breaking waves. The water returns to the sea which in turn drives a turbine. Images created by Aqua-RET.*

3.1 Mechanisms of impact to kelp communities

From a review of publicly available information on different wave energy technologies, it is possible to establish the overlap between activities associated with different technologies sharing common features (i.e. open-water, seabed mounted and shore-based devices) and kelp communities. Sub-tidal kelp habitats can be considered to occur on rocky substrata between 0 and 30 m below chart datum (Smale et al., 2013). Table 2 describes the activities that are widely applicable to most technologies, highlighting features of the activity including depth, duration, impact type and spatial extent. In addition to establishing the extent of possible overlap, the following sections address the contribution that different technologies may make to the future wave energy industry as a whole. Furthermore, the most relevant activities associated with different technologies sharing common features have been highlighted.

Table 2: An overview of activities associated with wave energy projects with reference to the mechanisms of impact to kelp communities. Each wave energy project will likely result in a unique combination of activities listed. These are dependent on the technology used as well as the characteristics of the site and resources available. Example estimates of the maximum footprint per device are taken from Royal Haskoning (2012). However, these estimates are taken from one specific project and other projects would have to consider their footprint on a case-by-case basis.

Project phase	**Activity**	**Description**	**Depth**	**Impact**	**Impact duration**	**Example estimates (per device)**
Construction	Securing jack-up barge	Installation of WECs within shallow water sites requires the use of a stable working platform (jack-up barge). Once positioned, the legs of the barge are forced onto the seabed resulting in the vessel being lifted from the water. The benthic community under each leg will be lost temporarily and must recover once the vessel is redeployed.	10-40 m	Disturbance	Largely recoverable within 5 years	20-40 m^2
Construction	Site preparation	The aim of this activity is to modify the seabed to ensure that it is stable and promotes the effective working of the device. Site preparation is likely to take the form of total kelp removal and seabed levelling works. Kelp removal may be undertaken by divers or by machine. The extent of seabed levelling activities depends on the outcome of micro-siting activities. Where used, seabed levelling will involve the removal and breaking of rock in addition to the instalment of gap fillers (rock or graded rock contained within wire cages).	10-40 m	Disturbance/ habitat replacement	Disturbance largely recoverable within 5 years. Temporal impact of habitat replacement depends on the duration of the project and maintenance schedule.	1000 m^2

Construction	Piling and drilling	Where used, a mono-pile socket is typically drilled into the seabed from the jack-up barge. Drilling methods used will make use of sea water and the drilling fluid, and all drill cuttings will remain at the site before becoming naturally dispersed. A steel pile is then inserted into the socket and this will be grouted into place. There is a potential loss of grout to the sea during routine grouting operations and flushing out of the grout hoses. However the amount of grout being pumped into the socket will be monitored from the surface and by divers and it is predicted that approximately 1 m^3 of grout may be lost from each operation (Royal Haskoning, 2012).	10-40 m	Habitat loss/ disturbance/ contamination	Habitat loss depends on the duration of the project. Disturbance largely recoverable within 5 years assuming no repeated removal of kelp. Contamination likely to be dispersed quickly within days.	20 m^2
Construction (and operation & maintenance)	Installing devices	Installation of WECs will require the securing of devices to mono-pile structures or similarly secure structures including rock anchors, anchors and mooring blocks. Some devices will also contain structures used to secure inter-array pipeline and/or cabling. Such structures will almost certainly be contained within the previously prepared sites and will continue to undergo some form of disturbance during routine maintenance operations to ensure the proper running of the device.	10-40 m	Habitat replacement	Habitat replacement depends on the duration of deployment and maintenance schedules (recovery within approximately 5 years assuming no repeated removal of kelp).	340 m^2
Construction	Installing mooring anchors	The installation of moorings and anchors around the device is required for some operations to take place. The level of disturbance associated with each anchor or mooring will depend primarily on the type of anchor or mooring used.	10-40 m	Habitat loss/ disturbance/ habitat replacement	Habitat replacement depends on the duration of the project (approximately 20 years) and maintenance schedules.	8 m^2

Construction	Installing cabling	The type of cable used will depend on the type of WEC used. Where devices circulate water to and from shore a cable will normally be installed adjacent to the pipelines and therefore will not produce an additional disturbance. Devices in deeper water will also require a cable to be run ashore. Rocky shores are commonly cited as being a more challenging environment to run a cable ashore as rocky high energy environments will require additional work to protect cables (Department For Business Enterprise and Regulatory Reform, 2008). Where directional drilling is used to make land fall, disturbance to kelp communities may be largely avoided. However, for nearshore devices some degree of inter-array cabling may be required. Cables that are less protected and/or responsible for high levels of power transmission may produce a strong electromagnetic field. (Gill et al., 2009, Normandeu-Associates-INC et al., 2011)	0->50 m	Disturbance/ habitat replacement/ Electro-magnetic field generation	Disturbance largely recoverable within 5 years. Habitat replacement and electromagnetic field generation depend on the duration of the project (approximately 20 years).	Variable
Construction	Installing inter-array pipelines	WECs that circulate water to and from the shore require a complex network of pipes to be assembled. For large arrays a common pipeline assembly will be constructed to collect high pressure water from a shorter pipe running to each device. A range of connectors may be necessary for some projects, increasing the width of the pipeline assembly.	10-40 m	Disturbance/ habitat replacement	Disturbance largely recoverable within 5 years assuming no repeated removal of kelp. Habitat replacement depends on the duration of the project (approximately 20 years).	Variable
Construction	Installing export pipelines	Directional drilling may be used to create a route to a site or device. Where directional drilling is prohibitively expensive or inappropriate, the construction of a pipeline corridor is necessary.	0-40 m	Disturbance/ habitat replacement	Disturbance largely recoverable within 5 years. Habitat replacement depends on the duration of the project (approximately 20 years).	Variable

Construction	Pipeline and cable stabilisation and protection	To ensure that all cables and pipelines are safely installed and protected in these high energy environments will require a range of additional disturbances to take place. This process will require the installation of cables and/or pipework by employing a combination of site preparation, dredging, fixing, armouring, rock mattressing and rock dumping techniques. It is likely that this activity will have the largest footprint of all activities associated with the exploitation of wave energy resources. Kelp habitats may be disturbed and subsequently replaced by a range of rock and artificial structures i.e. concrete, metal and plastic.	0 m-off-shore	Disturbance/ habitat replacement	Disturbance largely recoverable within 5 years. Habitat replacement depends on the duration of the project (approximately 20 years).	Corridor width has been quoted at 10 m. One nearshore project quoted 720 m^2 per device
Operation & Maintenance	Energy extraction	Local changes in hydrodynamics may result from the partial or complete removal of wave energy due to energy extraction. Some devices are more efficient at removing energy from certain wave lengths and heights. It is anticipated that where the vast majority of waves are removed regardless of their characteristics (e.g. creation of a breakwater) hydrodynamics will be greatly altered on the landward side of these projects.	0-40 m (0-10 for devices that require a breakwater [e.g. Oscillating Water Column device])	Altered community composition	Altered community composition depends on the duration of the project (approximately 20 years).	Variable
Operation & Maintenance	Maintenance	Maintenance will likely result in small disturbances to the seabed. The frequency will depend on the technology employed and the success of engineered components. Where they are used, antifoulant coatings will reduce the amount of colonisation. However, there will be a limit to their effectiveness over time, with the potential need for re-application. Activities may involve removal of kelp for routine inspections or the replacement of devices requiring on-shore attention.	10-40 m	Disturbance	Disturbance largely recoverable within 5 years assuming no repeated removal of kelp. *L. hyperborea* unable to recover when repeat clearing intervals are < 2 years	Variable
Decommissioning	Partial or complete removal of seabed infrastructure	Decommissioning will likely result in the partial removal of all underwater structures. It is likely however that cabling will remain in place as its removal would be prohibitively expensive.	As for installation	Disturbance	Disturbance largely recoverable within 5 years.	Variable

3.1.1 Deep-water moored Wave Energy Converters

A large number of WECs have been developed to exploit wave energy resources at sites that are too deep to maintain kelp communities (i.e. deeper than 40 m) (RSK Environmental Ltd, 2012, Scottish Power Renewables, 2012). A degree of disturbance to nearshore kelp communities can still be expected from associated activities such as cable installation (Table 2). Relative to other approaches of extracting wave energy (i.e. shore-based and shallow water energy converters), these activities are likely to result in low levels of disturbance to kelp communities as the direction of installation would likely be perpendicular to the shoreline and associated zonation, representing the shortest route through kelp communities where present. Additionally, disturbance relating to the installation of a cable (and stabilisation material) will be temporary with recovery of the community expected over time (section 4.3). There are potential indirect effects such as the alteration of kelp communities due to the removal of wave energy on the shoreward side of the development (section 4.5). However, the direct impacts for projects exploiting wave resources in water deeper than 40 m are therefore likely to be small relative to other approaches.

3.1.2 Shore-based Wave Energy Converters

Shore-based WECs such as those that may require the modification of the shoreline and in some recent proposals, the creation of a new shoreline in deeper water (Xodus Group, 2012) are potentially of greater concern as the devices and infrastructure may be deployed directly within high-energy rocky subtidal environments which support kelp communities. Impacts to kelp may result from site preparation of the coastal environment, installation of devices and infrastructure. In the majority of cases, projects may only require a modest modification to the existing shoreline. However, where projects require the extensive modification of the coast (e.g. the creation of a breakwater on the seaward side of kelp habitats) the loss of kelp habitats, in addition to irreversible changes to the physical environment, may impact kelp communities greatly. The activities associated with these technologies are project- and technology-specific, and the resulting environmental impacts on kelp communities should be considered on a case-by-case basis (Table 2). The contribution that these technologies may make to the future wave energy industry as a whole is uncertain. It is of note that there are challenges around economic viability of these technologies as the design of customised devices may lead to overburdening set-up costs compared to easily reproducible designs (Figures 4 & 5). Consequently, this review assumes that future technologies fitting this description will make a smaller contribution to the wave energy industry as a whole and the risk assessment reflects this (section 5).

3.1.3 Shallow-water Wave Energy Converters

Shallow-water areas (10 - 30 m), are suitable for point absorbers, oscillating wave surge converters and submerged pressure differential devices (Figure 5) (Folley et al., 2005, Xodus Group, 2011, Aquatera, 2013). There is a wide overlap between activities associated with these shallow-water WECs and kelp communities. This is due to the potential for the extensive deployment of infrastructure directly within areas likely to support kelp communities. Kelp biomass will be lost either intentionally from activities such as site preparation and/or habitat replacement or incidentally during activities such as securing a jack-up barge and/or deploying infrastructure. It is useful to separate disturbance into two impact descriptions: the intentional or accidental loss of biomass from kelp communities (defined here as disturbance) and the addition of new substrata to kelp habitats. These are treated separately since they are likely to have different outcomes. Full 'habitat loss' may occur in areas where kelp communities cannot/are prevented from re-colonising the substrate, for example mono-piling. However, in most situations kelp which has been removed from the rock will then be able to either re-colonise the existing rock or a range of artificial substrates which have replaced the existing habitats (e.g. metals, plastics, concrete and rock). The re-colonisation of both algae and invertebrates that constitutes 'kelp communities' will depend on the outcome of interactions with the novel substrata. These are likely to depend on the degree to which the new substrates reflect the 'natural' surrounding habitats supporting kelp communities. For example, large rock used to secure cable and pipes may maintain a large number of the characteristics of the surrounding rocky habitats, whereas smooth mobile metal structures retain few natural characteristics.

In addition to substrate type, re-colonisation may depend on the timing and extent of kelp removal as well as the physical and biological characteristics of the environment. Many of the large disturbance events will occur once during the construction phase (and again during decommissioning). Furthermore, there may also be disturbance of kelp communities during routine maintenance activities including the removal of kelp and associated species to access, inspect and maintain devices and infrastructure. Compared to construction activities, maintenance activities are likely to result in comparatively low levels of disturbance as activities will target small areas where kelp removal is deemed necessary.

As the cost and complexity of tasks associated with this industry are likely to be dependent on the prevailing sea conditions, it is reasonable to assume that operators will attempt to undertake the majority of tasks, both construction and maintenance, during good weather periods. Therefore it can be assumed that a large majority of disturbance associated with activities will occur during summer months. This departs from the natural cycles of disturbance to kelp communities which are greatest during winter months (Orr, 2013, Walker and Richardson, 1955).

4. REVIEW OF ECOLOGICAL IMPLICATIONS OF KELP REMOVAL

4.1 Overview

The deployment of WECs may directly impact kelp communities via two main pathways:

1) Complete loss of kelp habitat, whereby the kelp community is permanently replaced by a structure that is not re-colonised by kelp (e.g. mono-piling and construction of a breakwater in the kelp zone)

2) Disturbance, of varying intensity, either short- or long-term, during which kelp communities may temporarily be removed and undergo a series of successional changes and/or recovery. The nature of the disturbances falls under three categories:

(i) Accidental or deliberate removal of kelp biomass from natural rock habitats involving periodic kelp removal.

(ii) Replacement of benthic habitat by either quasi-natural rock or unnatural substrate e.g. plastic that is re-colonised by kelp.

(iii) Habitat fragmentation

Furthermore, WECs may have indirect impacts to adjacent ecosystems including, but not limited to, changes in wave energy reaching the shore, changes in sediment dynamics altering sedimentation rates, shading from WECs, changes in food-web structure and altered nutrient cycling.

4.2 Complete loss of kelp habitat

Removing kelp and/or rock from the seabed and replacing that area with a new structure (e.g. mono-pile) that is not re-colonised by kelp will result in a direct and permanent loss of the kelp, including all the flora and fauna that are living within/on the kelp holdfast, stipe and fronds (Christie et al., 1998). There would simultaneously be a loss in understorey flora and fauna such as red seaweeds, various anemones and ascidians. Mobile fauna such as starfish, urchins and fish may be displaced. The major species that would be impacted by the loss of kelp habitat are detailed in section 2.3 (review of kelp communities) and Annex 1. Estimates for one project of the maximum area of kelp habitat lost, per WEC device for periods of approximately 20 years, are between 200-400 m^2 (Table 2). This figure includes the area of kelp habitat which is replaced by the WEC and assumes the frequency of continued disturbances caused through maintenance activities (e.g. device removal and replacement) will result in the exclusion of kelp from this area for the duration of the project.

4.3 Disturbances to kelp habitats

4.3.1 Periodic kelp removal

Disturbances created by routine kelp clearing and/or accidental removal would result in the immediate and localised loss of kelp biomass, followed by a period of recovery. Kelp forests may recover from disturbances once environmental conditions are favourable such as when there is sufficient light, nutrients, stable bedrock and little grazing pressure (e.g. from sea urchins). The recovery of disturbed kelp habitats (e.g. after clearing/harvesting) depends on the re-colonisation rate of the kelp itself (settlement and growth of juvenile sporophytes), as well as the re-colonisation rates of associated flora and fauna (Christie et al., 1998, Waage-Nielsen et al., 2003). In general, there is considerable spatiotemporal variation in the recovery rates of kelp-dominated communities (Christie et al., 1998, Dayton et al., 1992), as reviewed in section 4.4.1. Kelp canopy structure (age and density) vary with latitude (Rinde and Sjøtun, 2005), and therefore recovery patterns vary with latitude along the coast (Christie et al., 1998). In Norway it was found that kelp plants were significantly older and larger at more northern latitudes (Christie et al., 1998), and the kelp canopy and associated flora and fauna took longer to recover after harvesting at a higher latitude (63° N) versus a lower latitude (59° N) (Christie et al., 1998).

4.3.2 Introduction of new surfaces

One of the main impacts of installing WECs will be the introduction of artificial (i.e. man-made) substrates such as rock-mattressing, anchors, pipelines and the device itself. Many of these artificial substrates are fundamentally different from natural habitats as they may have predominantly vertical surfaces rather than horizontal and/or are made of different materials such as plastic, metal and concrete. Therefore, artificial substrates may support assemblages of organisms that are different from the natural kelp community, including the facilitation of non-native species (Marzinelli et al., 2011). Artificial environments such as smooth concrete tend to have reduced environmental heterogeneity with fewer crevices and pits (on a scale of 1-10 cm) that may provide refuges for species (Firth et al., in press). As such, they often have a lower biodiversity of attached species than natural substrates (Firth et al., in press).

Kelp can colonise a variety of artificial substrates such as concrete blocks (Jones and Kain, 1967, Kain, 1975), wood (Marzinelli et al., 2011) and various plastics (Pers Comm, Philip Kerrison, Scottish Association for Marine Science). Rock-mattressing and rock-dumping may have the largest footprint of all activities associated with the installation of WECs. Rock mattresses have important habitat-forming value because they mimic natural boulders and provide a fairly complex habitat for successful attachment (Firth et al., in press). In the intertidal zone, the size of the stones within the mattress (ranging from 6 cm to large rocks > 18 cm) does not affect the diversity of colonising species (Firth et al., in press). However, Firth et al. (*in press*) found that the abundance of organisms is generally greatest on mattresses with smaller stones. To allow for the regrowth of climax kelp communities it would be necessary to ensure that new habitat created is secure (e.g. for the rocks contained within the wire frame of the mattress to be tightly secured) thereby providing a relatively stable substrate for kelp regrowth. Many algae spores are not selective in their settlement and successful recruitment depends on factors such as cover of other algae and post-settlement survival (Kain, 1975). Therefore, artificial substrates could potentially sustain populations of kelp and their associated species provided that the habitat complexity and surface characteristics of the substrate matched the natural environment as closely as possible.

4.3.3 Habitat fragmentation

Clearing kelp for the installation of WECs will create bare areas and/or introduce new substrates which fragment parts of the kelp habitat. The individual cleared areas will range from ~ 20 m^2 to 1000 m^2. The successful dispersal of fauna between and within this fragmented habitat will depend on the size of the cleared area as well as the dispersal abilities of fauna associated with kelp (Waage-Nielsen et al., 2003). Most fauna associated with kelp are able to disperse rapidly across cleared areas and tracks that are more than 10 m wide (Waage-Nielsen et al., 2003). A study in Norway found that 87% of mobile species within large cleared areas (~ 5000 m^2), were able to re-colonise suitable substrates (e.g. nearby kelp holdfasts) within 35 days (Waage-Nielsen et al., 2003). This suggests that it is unlikely that habitat fragmentation by WECs will negatively impact the dispersal abilities of fauna associated with kelp forests.

4.4 Impacts to species diversity

Kelp forests are complex three dimensional habitats akin to rainforests and provide a variety of habitats in which other organisms can hide, feed on/in or attach themselves to (Bartsch et al., 2008, Moore, 1974, Norderhaug et al., 2012). The cover of kelp (specifically *L. hyperborea*) is the major driver of biodiversity on subtidal rock in the UK (Burrows, 2012). The following section reviews how the removal of kelp may impact the biodiversity of flora and fauna within kelp biotopes and the rate at which they can recover from disturbances. The findings of the review are summarised in Table 3.

4.4.1 Impacts to the kelp canopy

After clearing adult kelp, a new generation of *L. hyperborea* can rapidly establish and return to virgin forest biomass and height within 2-5 years (Kain, 1975, Christie et al., 1998). Kelp forests recover most rapidly if the rock surface is not scraped entirely clean of all understorey algae and small kelp recruits (Kain, 1975). A year after kelp forests are removed, fast-growing opportunistic algae are usually most abundant (section 4.4.2) and *L. hyperborea* dominates 2-3 years after the initial clearing (Kain, 1975). Recovery of the kelp forest is slightly slower and more variable at depths greater than 4 m and here it may take more than 2 years for *L. hyperborea* to dominate the biomass (Kain, 1975). Kelp forests may take longer to re-establish and grow in deeper water because of grazing from urchins, e.g. *Echinus esculentus* (Kain, 1975) and due to reduced light penetration (Luning, 1971). The season in which kelp is cleared (summer, autumn, winter, spring) does not have a strong effect on the rate of recovery to virgin biomass and similar patterns of species succession are observed for all seasons (Kain, 1975, Christie et al., 1998). Repeatedly clearing areas of kelp forests at intervals of less than 2 years will not allow long-lived kelps such as *L. hyperborea* to re-establish while clearing persists. However, once clearing is terminated the climax kelp community (i.e. dominated by *L. hyperborea*) is likely to return within 2-3 years (Kain, 1975). Repeated clearing, at 5-6 year intervals may lead to the development of a very dense, homogenous kelp forest with lower species diversity (Christie et al., 1998).

Removal of the mature kelp canopy allows more light to penetrate the understorey which stimulates rapid growth of the small kelp recruits (Christie et al., 1998). Small kelp recruits generally persist in the understorey for several years, and thus the regrowth of kelp after clearing does not solely depend on the recruitment success the year of clearing (Christie et al., 1998). The ubiquitous presence of kelp sporelings in the canopy understorey ensures the maintenance of kelp forests (*L. hyperborea*) even with repeated kelp clearing every 5-6 years (Christie et al., 1998). If rock surfaces are sterilised or new clean surfaces are introduced then the kelp-dominated community is likely to only re-establish following the reproductive season of kelp (winter) (Kain, 1975).

Table 3: Time taken for various members of the kelp forest community to recover to original densities, and effect of season and repeat clearing on the recovery of flora and fauna.

Flora/fauna	Impact	Recovery period	Season of clearing	Repeat clearing
Kelp	Immediate loss of canopy species, *L. hyperborea*	2-5 years to reach original canopy height and biomass[1,2]	No effect on recovery	*L. hyperborea* unable to recover when repeat clearing intervals are < 2 year[2].
Understorey flora	Outbreak of opportunistic seaweed species (*Desmarestia spp*. and *Saccorhiza polyschides*) in first 6 months to 1 year[2]	Opportunistic species replaced by canopy species within ~ 1 year[2]	Colonisation greatest in summer months[2]	Opportunistic algae persistently dominate when clearing intervals are < 1 year[2]
Understorey fauna	Possible encroachment of sea urchins into cleared areas, which may inhibit regrowth of kelp via grazing of juvenile seaweed[4]	Dependent on the abundance of urchins[4]	Unknown	Unknown
Epiphytes	Immediate loss of species attached to kelp	5 years to reach ~ 80% original density[1]	No effect on recovery	Do not recover to original diversity when repeat clearing intervals are < 5 years[1]
Holdfast fauna	If holdfast is removed, then there will be an immediate loss of holdfast species. Some fauna may seek refuge in adjacent kelp or under stones[5]. If holdfasts are left intact then fauna will be less disturbed.	~ 1 year for polychaetes, gastropods and species with pelagic larval dispersal to reach maximum densities on new holdfasts[1] > 6 years for species with limited dispersal (e.g. isopods) to reach maximum densities[1]	No effect on recovery	Do not recover to original diversity when repeat clearing intervals are < 5 years[1]
Fish	Decline in abundance of juvenile fish within cleared areas. Migration to kelp-forested areas likely[3]. No change to abundance of adult fish in cleared areas[3].	Juvenile fish return once kelp habitat regenerates[3].	More vulnerable during recruitment period (spring)	Unknown
Birds	Unknown. However, kelp removal may impact diving birds, such as cormorants, by altering their familiar feeding habitat and through a reduction in fish abundance.	Unknown	Unknown	Changes in feeding patterns likely.

[1] (Christie et al., 1998), [2] (Kain, 1975), [3](Lorentsen et al., 2010), [4](Norderhaug and Christie, 2009), [5](Waage-Nielsen et al., 2003)

4.4.2 Impacts to understorey flora (opportunistic seaweeds)

Clearing kelp typically results in outbreaks of understorey algae such as the opportunistic brown seaweeds *Desmarestia viridis* and *D. aculeata,* and the short-lived kelps, *Alaria esculenta* and *Saccorhiza polyschides* (Kain, 1975). The biomass of these opportunistic species peaks in the summer months after clearing (Kain, 1975). In the shallow intertidal zone, the rocks may be immediately colonised by green algae, such as *Ulva* and *Enteromorpha spp.* (Kain, 1975). As colonisation progresses towards climax vegetation (i.e. dominated by *L. hyperborea*) these opportunistic species are virtually eliminated (Kain, 1975).

4.4.3 Impacts to understorey fauna (sea urchins)

Sea urchins are the major herbivorous grazers within the understorey of kelp forests and play a key role in regrowth of the kelp (Chapman and Johnson, 1990, Dayton et al., 1998),. Urchins naturally inhabit kelp forests at low densities (Jones and Kain, 1967) but may experience population booms, the reasons for which are not fully understood in the north-east Atlantic (Norderhaug and Christie, 2009). Urchins graze heavily on juvenile kelp and can dramatically transform kelp-dominated habitats into barren grounds of coralline algae which can persist for decades (Dayton et al., 1998, Norderhaug and Christie, 2009). A shift to barren grounds will result in a loss of productivity and biological diversity (Norderhaug and Christie, 2009).

Removing kelp to form large ‘gaps’ in the canopy of > 20 m^2 may result in the encroachment of urchins, which form circular fronts around the edge of the gaps (Lauzon-Guay and Scheibling, 2010). If several patches of kelp have been cleared, then these gaps may coalesce and expand as a result of urchin grazing. Kelp clearing that coincides with a boom in urchin populations may result in widespread destruction of the kelp forest (Sivertsen, 1997 Lauzon-Guay and Scheibling, 2010, Feehan et al., 2012). However, urchin barrens most commonly occur in areas where predators such as otters, lobsters and fish (cod) have declined as a result of over-exploitation (Tegner and Dayton, 2000, Steneck et al., 2002) documented for the north-west Atlantic (Chapman and Johnson, 1990, Steneck et al., 2002) and the north-east Pacific (Steneck et al., 2002, Estes et al., 2004). Urchin barrens have also been reported in the north-east Atlantic and have been described as one of the largest ecological catastrophes in Norway (Norderhaug and Christie, 2009).

It is unclear whether there is any potential for urchin barrens to develop within areas that have been cleared of kelp for the installation of WECs in the UK. The main culprit for over-grazing in temperate kelp forests is the green sea urchin *Strongylocentrotus droebachiensis* (Norderhaug and Christie, 2009) which is not common in UK waters (Russel, 2001). The red sea urchin *Echinus esculentus* is most abundant in Britain and has been found in high densities within kelp forests in Scotland (Jones and Kain, 1967). However, there is no evidence that *E. esculentus* has created barren grounds in British waters to date (Comely and Ansell, 1988, Wilkinson,1995). In addition, urchins tend to avoid areas of strong wave exposure (Himmelman, 1986), further reducing the chance of barren grounds developing in areas where WECs are installed.

4.4.4 Impacts to epiphytes

Kelp epiphytes are immediately lost when kelp is cleared from an area. Epiphytes take ~ 2-3 years to re-establish on the new generation of kelp and recover to ~ 80% of their pre-clearing density within 5 years (Christie et al., 1998). Full epiphyte recovery depends on the establishment of mature kelp and thus a site subjected to repeat kelp clearing every 5-6 years is unlikely to fully recover its epiphytic abundance and diversity (Christie et al., 1998). Epiphytes are an important secondary habitat to many invertebrates such as amphipods (Christie et al., 2007) and a reduction in epiphytic abundance will slow the recovery of other fauna within cleared areas (Christie et al., 1998).

4.4.5 Impacts to holdfast fauna

The diversity and abundance of fauna inhabiting kelp holdfasts will initially decline in the immediate vicinity of kelp clearance. Some mobile fauna may seek refuge in adjacent kelp and under boulders and cobbles (Waage-Nielsen et al., 2003). One year after kelp removal, as kelp regenerates, a relatively high number of species and individuals may inhabit new holdfasts, and the re-colonisation rate typically increases as the holdfast continues to grow (Christie et al., 1998). The rate at which different taxa re-colonise the kelp or new substrates depends on their dispersal abilities and reproductive strategy and slow-moving fauna are more vulnerable to the impacts of kelp removal. The most rapid colonisers are amphipods that are strong swimmers and gastropods that can drift in the water column (Waage-Nielsen et al., 2003). Slower colonisers include sessile fauna (mussels) and those that reach new habitats by weak swimming and/or crawling such as polychaetes and isopods (Waage-Nielsen et al., 2003). Fauna with pelagic larval settlement (e.g. gastropods) recover to maximum densities one year after clearing (Christie et al., 1998, Waage-Nielsen et al., 2003). Longer periods (> 6 years) are required for the full recovery of fauna that reproduce by brooding (Christie et al., 1998). The season of kelp clearing has no effect on the recovery of holdfast fauna (Waage-Nielsen et al., 2003).

4.4.6 Impacts to higher trophic-level fauna (fish and birds)

The removal of kelp habitat may trigger an immediate, localised reduction in juvenile fish due to the loss of shelter and food (Bodkin,1988, Lorentsen et al., 2010) . Juvenile fish within the cleared areas may become easy targets for predatory fish and birds (e.g. cormorants) and it is likely that many small fish migrate to the nearest kelp-forested areas to seek refuge (Lorentsen et al., 2010). Where large quantities of *L. hyperborea* were removed (~15 000 metric tonnes) in Norway, the abundance of small (< 15 mm) gadoid fish was 92% lower in cleared areas versus kelp-forested areas (Lorentsen et al., 2010). This Norwegian study also found that large fish (> 15 mm) were less severely impacted by kelp removal and abundances were similar in cleared and forested areas (Lorentsen et al., 2010). The area of kelp likely to be cleared for wave energy devices will be an order of magnitude lower than for commercial kelp harvest in Norway and thus impacts to fish are likely to be considerably less than those reported by Lorentsen et al. (2010).

Kelp removal may impact diving birds such as cormorants by altering their familiar feeding habitat and through a reduction in fish abundance (Lorentsen et al., 2010). However, such changes would be difficult to detect because of the large amount of natural variability in seabird feeding patterns and due to multiple variables at play (Grémillet and Charmantier, 2010). In Norway it was found that birds performed significantly more dives in kelp-forested areas versus cleared areas suggesting that removal of kelp habitat is associated with a reduction in bird foraging efficiency (Lorentsen et al., 2010). Marine birds memorise their optimal feeding habitats (e.g. kelp forests), and it is likely that they will need time to familiarise themselves with the altered habitat once WECs are installed and find opportunities to feed elsewhere if necessary (Lorentsen et al., 2010). There is currently insufficient work being undertaken to explore interactions between kelp communities and marine mammals in the north-east Atlantic. However, it is likely that kelp habitats provide important foraging areas for many species of marine mammal (Duggins, 1980).

4.5 Impacts to habitat functionality and ecosystem services (Indirect effects)

Kelp forests provide several important ecosystem services (Smale et al., 2013) which extend beyond the kelp ecosystem themselves. These include, but are not limited to: provision of habitat to a multitude of species; the cycling and sequestration of carbon (Laffoley and Grimsditch, 2009); nutrient cycling (Smale et al., 2013); magnification of secondary production (Duggins et al., 1989, Krumhansl and Scheibling, 2012, Smale et al., 2013) and prevention of coastal erosion through buffering of wave energy (Mollison, 1983, Wolf and Woolf, 2005). These ecosystem services may be impacted by kelp removal, depending on scale and intensity. These functions may also be impacted by the presence of the WECs themselves.

As outlined in section 4, kelp forests are repositories for biological diversity and serve as an essential habitat to fauna in wave-exposed environments. In addition, kelp continually produces detritus via the scouring of fronds and loss of biomass during storms (Krumhansl and Scheibling, 2012) and this detritus is exported to adjacent ecosystems where it is consumed by a variety of fauna (Krumhansl and Scheibling, 2012). Kelp detritus has been found to enhance the secondary production of fauna in habitats ranging from terrestrial environments (Polis and Hurd, 1996), sandy beaches (Dugan et al., 2003), rocky shores (Bustamante and Branch, 1996) and deep-sea canyons (Vetter, 1998). Kelp forests also use CO_2 to grow and leach non-reactive dissolved organic carbon (DOC) into the water which circulates in the oceans for thousands of years (Hughes et al., 2012). Therefore kelps play an essential role of the sequestration of CO_2.

Coastal defence is one of the most important services supplied by kelp forests, which dampen and attenuate wave energy and thereby protect the coast from erosion and alleviate the damage caused by storm and flooding events (Løvås and Tørum, 2001, Smale et al., 2013) . In regions with dense kelp forests (e.g. Outer Hebrides) wave power losses of 54% have been recorded between depths of 100 m and 15 m, with the greatest losses in energy experienced between 23 m and 15 m depth where kelp forests are abundant (Mollison, 1983). Off Norway, forests of *L. hyperborea* have been found to reduce wave heights by up to 60% (Mork, 1996). The estimated area of kelp habitat disturbed and/or lost per installation of each WEC was estimated to be in the region of 2000 m^2 or more (sum of predicted areas of disturbance/loss of kelp in Table 2). Natural disturbance or loss of kelp during winter storms occur across tens to hundreds of km^2(section 4.6) therefore it is expected that the installation of each WEC is unlikely to have a significant effect on coastal erosion in comparison to natural fluctuations in kelp biomass.

The WECs themselves are likely to have the greatest effect on the quantity of wave energy reaching the shore (Shields et al., 2011), the full impact of which is beyond the scope of this report. In brief, individual WECs themselves will not extract large amounts of energy from waves but an installation of many WECs may alter wave height and change the hydromechanics of the environment on the shoreward side of the devices (Shields et al., 2011). In particular, a reduction in wave height of long waves will reduce the associated stress on the seabed and sediment re-suspension may be diminished (Shields et al., 2011). Variations in water flow and altered wave action may affect canopy-forming kelp such as *L. hyperborea* which are adapted to grow in high-energy coastlines at relatively shallow depths. A reduction in wave energy may favour other kelps such as *Saccharina latissima* and *Saccorhiza polyschides*, which prefer more sheltered environments but support a lower diversity of associated organisms (Burrows, 2012).

Kelp forests can be degraded by increased sediment input (Connell et al., 2008). Enhanced sediment deposition, for example due to dredging, smothers the kelp germlings and inhibits the recruitment of kelp (Devinny and Volse, 1978). Recruitment of kelp is further reduced by ‘abrasive scouring’ in areas with fast moving currents (Devinny and Volse, 1978). Canopy-forming kelp may be replaced by turf-forming species that trap large quantities of sediment (Connell et al., 2008). Severe smothering of kelp germlings occurs at ~100 mg sediment per cm^2 (Devinny and Volse, 1978). Vulnerable localities for enhanced sediment accumulation include rocky substratum that is low-lying or in close proximity to sand or is covered in turf-forming species (Connell et al., 2008). In areas with enhanced sedimentation there can be a habitat switch from kelp canopy to turf that may not be reversed for several generations of kelp canopy species (Connell et al., 2008). In order to resolve all likely impacts on kelp habitats, thought should be given to near- and far-field effects of changes in sedimentation rates as a result of the development.

Shore-based WECs, which require the modification or creation of a shoreline in a shallow infralittoral environment, will have a unique set of environmental impacts associated with these technologies. Where a new shoreline is created in front of an existing one, habitats on the shoreward side of the installation will be altered significantly due to a drastic reduction in wave energy and associated increased sedimentation rates. Such developments will also be associated with a degree of land-reclamation and in some cases this will result in the total replacement of infralittoral habitats with artificial environments in large areas of the seabed. Perhaps more importantly, large modifications to the existing shoreline may result in unpredictable changes in coastal geomorphology and changes in sedimentation rates in adjacent environments could result in changes to associated kelp habitats (Shields et al., 2011). Only through assessing the impacts associated with renewable energy projects at multiple scales can there be a clear picture of how such projects alter the surrounding environments (Miller et al., 2013). That said, detecting anthropogenic changes in a highly variable natural system over a wide area is extremely difficult and costly. Therefore future work investigating the environmental impacts of renewable energy would benefit from a better understanding of the degree of change to physical processes over large areas.

4.6 Placing impacts of installing WECs in perspective with natural disturbances to kelp communities

The response of ecosystems to disturbances whether natural or anthropogenic is scale-dependent (Edwards, 2004) and it is important to identify the scale(s) at which kelp communities are most strongly impacted by disturbances. Kelp forests are dynamic systems that undergo significant interannual and seasonal fluctuations in biomass (Walker and Richardson, 1955, Walker, 1956, Dayton et al., 1992) which can occur over tens to hundreds of kilometres in a year (Dayton et al., 1992, Edwards, 2004). The kelp canopy biomass may vary dramatically based on the availability of nutrients, light intensity, water turbidity, storm events, unstable substrate (e.g. rocks shifting during storms) and grazing pressure from herbivores (Dayton et al., 1992, Smale et al., 2013). In Scotland, winter storms can physically remove or scour about 34% of the kelp canopy biomass from the rocks each year (Walker and Richardson, 1955) and a further 26% is typically lost in early spring as a result of natural senescence (Walker and Richardson, 1955). High values of kelp canopy loss (39 - 71%) have also been recorded after hurricanes in the north-western Atlantic (Filbee-Dexter and Scheibling 2012) and near-to-complete removal of kelp from rocks has occurred during El Niño storms in the north-east Pacific after which kelp took up to two years to recover to pre-storm densities (Edwards, 2004). Anthropogenic disturbances related to the installation of each WEC are predicted to span across thousands of m^2 (Table 2) whereas natural loss of kelp canopy occurs each year across tens to hundreds of km^2. Therefore the impacts to kelp habitat per installation of WEC are expected to be relatively small compared to the natural perturbations that kelp habitats experience on a whole-ecosystem scale.

4.7 Wave energy technologies and non-native species

The creation of WECs may present opportunities for non-native species (NNS) which can disproportionately influence the functioning of the recipient habitats (Langhamer, 2013). These invasive species can produce deleterious ecological changes, displacing native species and/or altering habitat characteristics causing severe impairment of surrounding natural communities and important ecosystem services (Gray, 1997, Mack et al., 2000, Sala et al., 2000, Pimental et al., 2000, Crooks, 2002) .

Artificial structures, including those likely to be created by the large-scale creation of WECs can support large numbers of NNS (Page et al., 2006, Kerckhof et al., 2011). Structures supporting communities containing NNS may function as artificial islands facilitating the spread of NNS by providing refugia, particularly in those areas dominated by soft sediment and/or exposed environments (Bulleri and Airoldi, 2005, Sheehy and Vik, 2010). However, differences in habitat characteristics on artificial structures can have considerable implications for how these novel habitats and resulting communities may encourage the propagation of NNS (Bulleri and Chapman, 2010, Marzinelli et al., 2011, Mineur et al., 2012). For example, floating artificial structures have been observed to harbour greater numbers of NNS than artificial structures fixed to the seabed (Glasby et al., 2007, Dafforn et al., 2009).

This is particularly relevant to the wave energy industry as technologies tend to fall into one or the other category.

There are many reasons why some introduced species may prosper in a new environment including: escape from predators or parasites (Colautti et al., 2004); human-induced disturbance that can free limiting resources (Clark and Johnston, 2009); or in some cases the introduced species may possess a superior competitive ability or enhanced response to available resources (Shea and Chesson, 2002, Alpert, 2006). The substitution of natural environments, with artificial habitats created during the deployment of WECs can change the outcome of competitive interactions and in some cases could provide opportunities for NNS (Bulleri and Chapman, 2010, Mineur et al., 2012). The novel environments created by WECs contrast to natural habitats in terms of surface material, physical orientation and structure (Bulleri and Chapman, 2010). These unique niches will be unfamiliar to the evolutionary history of both native and NNS alike. Therefore, it is likely that the relative competitive outcomes of both native and NNS will be altered (Shea and Chesson, 2002, Marzinelli et al., 2011). For example, substrate recognition among fouling species is a key life-history characteristic used to select suitable conditions for subsequent survival and growth (Anderson, 1996, Harrington et al., 2004), NNS may have a competitive advantage on artificial substrates if native species have a reduced capacity to recognise the substrate or indeed recognise the substrate as a suboptimal niche (Tyrrell and Byers, 2007).

There is increasing recognition that once a NNS has been successfully introduced to an area it is highly unlikely that this process can be reversed (Ricciardi and Rasmussen, 1998, Kolar and Lodge, 2001). This has motivated ecologists to predict suitable habitats and forecast movements for many introduced species (Kolar and Lodge, 2001, Townsend, 2003, Herborg et al., 2007). Efficient management of the urbanised marine environment will benefit greatly from an ability to predict which artificial structures present the greatest risk of aiding the spread of NNS. However, no consensus has been reached regarding which factors (biological and physical) are most important for determining which activities will result in the greatest risk of providing opportunities for non-native species. Controlling introduction pathways (for example, examining the hulls of vessels with direct involvement in wave energy projects) has been suggested as one method to reduce their impact (Everett, 2000). However, the complexity and range of anthropogenic vectors transporting species from one place to another makes the control of introductions very difficult (Minchin and Gollasch, 2002, Ruiz and Carlton, 2003).

Ensuring wave energy companies follow best practice and comply with national legislation provides the best way to reduce the likelihood that activities associated with marine industries do not encourage the spread of invasive non-native species. In Scotland, amendments to Section 14 of the Wildlife and Countryside Act (Scottish Parliament, 2011) and the accompanying Code of Practice On Non-Native Species (Scottish Government, 2012) have significantly strengthened the law in relation to NNS. Two further offences have been added to the existing offence of releasing a non-native species from captivity. The new offences are:

- allowing an animal to escape from captivity outwith its native range, and:
- causing an animal to be in a place outwith its native range.

It may be possible to manage the likelihood that activities undertaken by the wave energy industry will introduce non-native species through ensuring the industry follows best practice which may involve the production of a biosecurity plan (Cook et al., 2014, Payne et al., 2014).

4.8 Summary of ecological impacts of WEC deployment on kelp communities

The deployment of WECs may directly impact kelp communities via permanently replacing the habitat with a structure (e.g. mono-pile) that is not re-colonised by the original kelp biotope. Kelp communities may also be subjected to temporary disturbances when the canopy is cleared for maintenance of site or infrastructure or when the benthic habitat is replaced by either quasi-natural substrate (e.g. rock-mattressing) or unnatural substrate (e.g. nylon-covered sandbags). Kelp can colonise a variety of artificial substrates such as concrete blocks and various plastics and grows best on new substrates that closely match the natural environment. Kelp re-grows rapidly and is able to reach virgin canopy height 2-5 years after clearing. However, kelp forests are unable to recover if repeat clearing occurs at intervals of 1-2 years and opportunistic seaweeds (e.g. *Desmarestia spp*. and *Saccorhiza polyschides*) will dominate. There will be an immediate loss in epiphytes and holdfast fauna if whole kelp is removed or is smothered by new substrates. Epiphytes take ~ 5 years to recover to ~ 80% of their original density and recovery periods for holdfast fauna ranges from 1 to > 6 years depending on species. There may be a decline in juvenile fish populations in cleared areas and a disruption to the feeding patterns of diving birds such as cormorants. The season during which kelp is cleared is unlikely to have a significant effect on the long-term recovery of the habitat. The indirect impacts of installing WECs may include changes in nutrient cycling and carbon sequestration, changes in nearshore food-web structure and altered hydrodynamics that may favour less diverse seaweed communities. Estimates from one project (Royal Haskoning, 2012) predict that approximately 200-400 m^2 of kelp habitat would be lost for periods > 20 years and approximately 1700 m^2 would be subject to temporary disturbances during the initial installation after which kelp habitats are likely to recover. In Scotland there is an estimated 10 million tonnes of *L. hyperborea* that has a typical extent of approximately 3600 km^2. Each year, these kelp forests lose roughly 34% of their biomass during winter storms and undergo seasonal fluctuations in biomass that stretch over tens to hundreds of kilometres of coastline.

5. OBJECTIVE RISK ASSESSMENT

There are a wide range of approaches to converting wave energy to electrical energy. For the purpose of this report these approaches have been grouped to include deep-water moored devices, shallow-water seabed-mounted devices and shore-based devices (see section 3). Although impacts to kelp communities resulting from wave energy projects should be considered on a case-by-case basis, the following sections attempt to assess the risk posed to kelp habitats through development of the wave energy industry at a national, regional and project site scale. Where impacts to habitats and species of conservation importance are possible, methods are discussed in which the evidence presented can contribute to risk assessments in existing management frameworks (i.e. EIA and HRA), focusing on the *significance* of impacts identified. A decision-tree is presented which is aimed at helping developers and environmental managers to consider the extent of impact that a specific technology and/or project may have on kelp habitats. Finally, recommendations are made for mitigation and best practice as well as suggestions for monitoring and areas for future research.

5.1 Expected scale of wave energy development in Scotland

At the time of writing, there are 11 planned wave energy lease areas at which an 'Agreement for Lease' has been issued by The Crown Estate. All are in different stages of planning and development and generally at an early stage. Details of the finalised proposals for most developments are unconfirmed.

Current projects are included within the Draft National Marine Plan for future wave energy development (data reproduced in Figure 1). Eight potential areas for further leasing for wave energy development have been identified in the Draft Sectoral Marine Plan for Offshore Wind, Wave and Tidal Energy (Scottish Government, 2013a). The proportion of the draft plan areas which will be developed as wave energy lease areas (and subsequent development) is currently unknown, though indicative occupancy rates of 0.2-1% are predicted (Scottish Government, 2013b). The extent and timing of the deployment of wave energy devices and the building of capacity in the current lease areas is also uncertain due to the challenges faced by the industry. In order to provide a meaningful assessment of the likely risks to kelp communities at a national scale, the focus of this report is on the current leasing round, with some qualitative reference to wider development in the draft plan areas.

From the project design work and scoping information available to date, it is likely that developments will be phased with initial phases occupying as little as 3 – 5 km^2 and future phases of projects potentially occupying 10 – 30 km^2 (Annex 3). The principal technologies which are currently being proposed are nearshore (1 – 2 km from the coast, e.g. Aquamarine Power Oyster 800) or intermediate offshore (3 – 12 km from the coast, e.g. Pelamis Wave Energy Ltd. P2). No shore-based devices are currently planned.

Recent models developed to predict the abundance of kelp throughout Scotland using data including bathymetry, depth, wave fetch and chlorophyll-*a* concentrations provide an estimate of the potential overlap with current wave energy lease areas (Burrows et al., in press). To produce digital maps, a statistical (ordinal logistic regression) model was fitted to abundance data for kelp generated from the Marine Nature Conservation Review (Burrows et al., in press). The model was then used to predict the areas where kelp should be found based on environmental characteristics of that area. For the purpose of this assessment, abundance was expressed as a 50% likelihood (P value) that the abundance would exceed a 'rare' abundance category using a SACFOR scale (R 1-5%, O 5-9%, F 10-19%, C 20-39%, A 40-79%, S >80%). Existing wave lease areas were then added to the base map. Polygons were rasterised in ArcGIS using the same 200 m grid as the kelp model (Figure 7). Each cell covers an area of 0.04 km^2 so the total number of cells in the lease areas with predicted kelp was 3575 which is equivalent to 44 km^2 (Burrows et al., in press). This is approximately 1.2% of the total area in Scotland (3600 km^2) where kelp has a 50% likelihood of being rare or more abundant. Therefore, if the developments proposed within the current lease areas are realised in the medium term, the estimated overlap between wave energy projects and the typical extent of kelp will be small (approximately 1.2%). The expected area of impact to the kelp biotope is likely to represent the much lower range of values, given that the actual footprint of individual devices will be far smaller than that of the designated area of an array. For example, for one wave energy project deploying infrastructure directly within the kelp zone, the extent of seabed alteration from all activities was estimated at 5.5% of the project area (the working footprint) (Royal Haskoning, 2012).

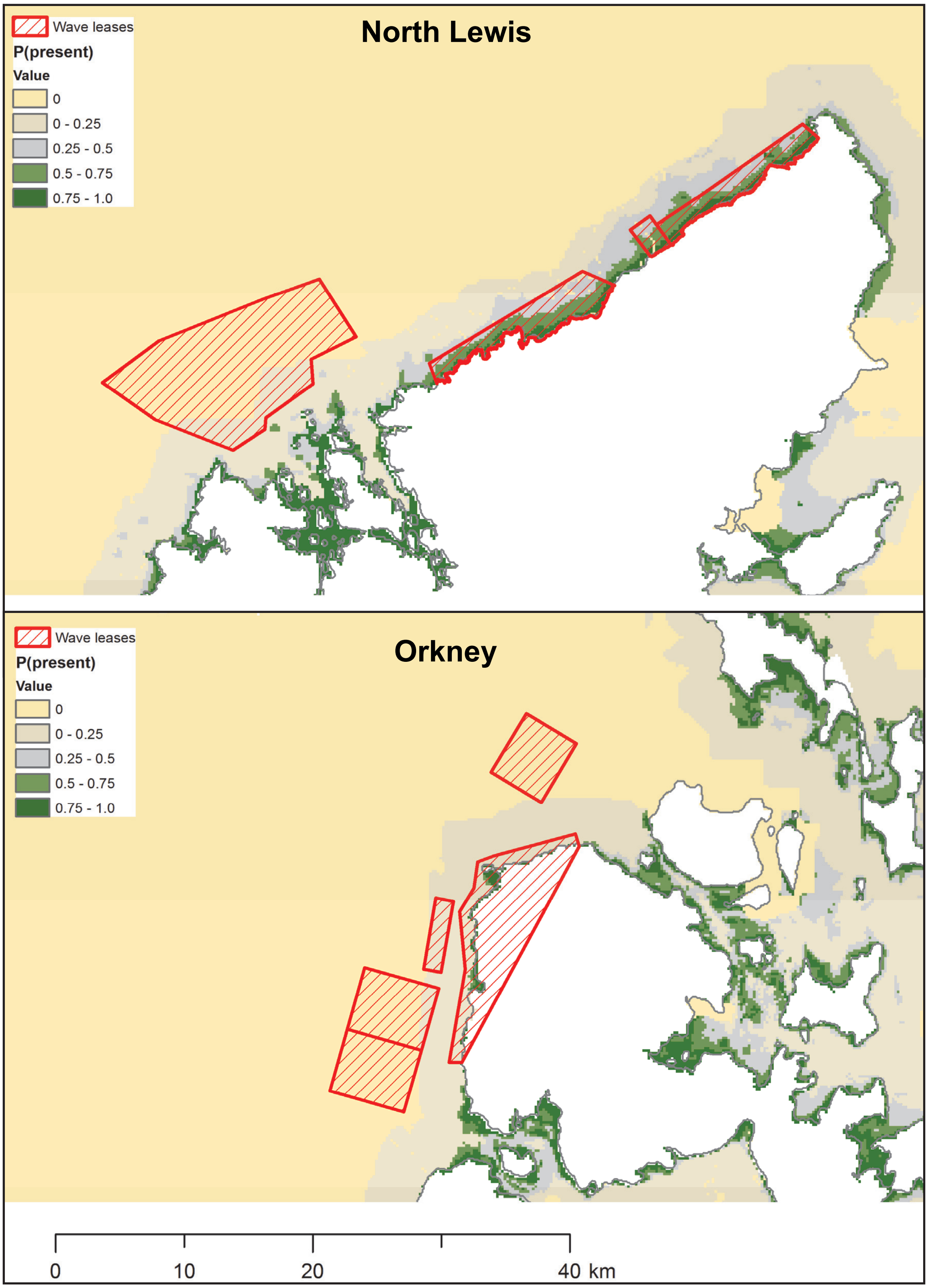

Figure 7. Extracts from the model (North Lewis and Orkney) showing the probability of finding kelp at a SACFOR abundance scale of Rare or more. *The current wave lease areas are shown in red. Data taken from* (Burrows et al., in press). P (present) value indicates the percentage chance of finding kelp at a SACFOR abundance scale of Rare or more.

5.2 Approach to an objective risk assessment

A basic approach to impact assessment and defining significance has been developed with reference to the IEEM Guidelines for Ecological Impact Assessment in Britain and Ireland in addition to the SNH Handbook for EIA (Institute of Ecology and Evironmental Management, 2010, Scottish Natural Heritage, 2013). A matrix approach is outlined, to present a consistent and logical framework for presenting the results of the risk assessment.

The significance of each impact is evaluated based on the sensitivity of the receptor, the nature and magnitude of the impact and the likelihood of the impact occurring. Criteria for sensitivity and magnitude depend on the pathway of the impact and the species at risk. The parameters used to support judgments on sensitivity, magnitude and consequence / significance in relation to kelp habitats are presented below.

Due to the range of WEC technologies and possible development locations in relation to kelp communities, it is not possible to conclude on the significance of impacts at a project level. In this assessment, the project-scale assessment considers the *potential* for a significant impact, which in most cases assumes that the project directly overlaps with these communities. In general, the significance of impacts will be lower for projects which are not directly associated with kelp communities and this would be established through EIA according to the specific project design.

5.2.1 Sensitivity

Sensitivity is a measure of the tolerance of a receptor to a predicted impact to which it is exposed, including its ability to recover. It is specific to the kelp biotopes reviewed and depends on the characteristics of the impact and associated predicted effect. As the majority of species responsible for creating kelp biotopes are themselves sedentary (i.e. the kelp itself), sensitivity is largely based upon the capacity for these species to adapt to, accommodate and/or recover from impacts, with avoidance not being possible. Table 4 outlines the descriptions that can be used to assign an overall sensitivity ranging from Negligible to Very High.

Table 4 Categories to support determining sensitivity.

Sensitivity	Definition
Very High	Lethal consequences (i.e. species forming kelp biotopes have no capacity to avoid, adapt to, accommodate or recover from the identified impact).
High	Potentially lethal consequences (i.e. species forming kelp biotopes have a very limited capacity to avoid, adapt to, accommodate or recover from the impact).
Medium	Non-lethal consequences identified (i.e. species forming kelp biotopes have a limited capacity to avoid, adapt to, accommodate or recover from the impact).
Low	No consequences identified (i.e. the community has the capacity to accommodate and/or recover from the impact).
Negligible	Kelp biotopes are generally tolerant to the anticipated impact.

5.2.2 Magnitude

The magnitude of impacts is based on the spatial extent, duration, frequency and severity of the change, considered against background variation and typical extent of species central to kelp biotopes. The magnitude of the impact is assessed at a national, regional and site scale. For the national scale, the reference extent for assessment of magnitude refers to the extent of kelp biotope(s) present within Scottish waters (approximately 3600 km^2). The regional scale refers to an intermediate scale of assessment, the magnitude of which is determined against likely regional kelp biotope resources present in areas of development (i.e. Orkney and Outer Hebrides). This scale may be useful in the consideration of cumulative impacts arising from multiple projects within a single region. Finally, the site scale refers to the localised impact at each wave energy project site.

Magnitude is quantified, as is reasonably practical and, where uncertainty exists, expert judgment applied. To support conclusions on magnitude *in lieu* of specific quantified assessment, a subjective scale has been used to assess impacts against available thresholds. The categories of magnitude used in this assessment are negligible, minor, moderate and major and the considerations used when assessing magnitude are presented in Table 5 (adapted from (Scottish Government, 2012b).

Table 5. Categories for determining magnitude.

Magnitude	Description
Major	Likely to have an irreversible impact on kelp biotopes, through exposure of > 5% of the typical extent.
Moderate	Likely to have an irreversible impact on kelp biotopes, through exposure of > 0.5% of the typical extent.
Minor	Likely to have a reversible impact (< 5 years) on kelp biotopes, through exposure of the < 5% of the typical extent.
Negligible	An imperceptible change to kelp biotopes (immediate recovery rates and/or spatial extent of impact is small relative to the typical extent).

5.2.3 Significance

The sensitivity of receptor and magnitude of impact are combined to define the significance of the impact as presented in Table 6.

Table 6. Matrix for determining significance of impact.

Magnitude	Sensitivity				
	Very High	High	Medium	Low	Negligible
Major	Major	Major	Major	Moderate	Minor
Moderate	Major	Major	Moderate	Minor	Negligible
Minor	Moderate	Moderate	Minor	Minor	Negligible
Negligible	Minor	Minor	Negligible	Negligible	Negligible

The overall conclusion on the significance of impacts is considered according to the descriptors given in Table 7. Where mitigation is required or is considered appropriate for reducing risk of individual impacts, this has been mentioned in the broad scale assessment presented in Table 8. As mentioned above, all impacts will need to be investigated more closely at the project level as impacts are specific to characteristics such as project location and WEC technology.

Table 7. Descriptions used for defining overall significance.

Significance	Description
Major	Highly significant and requires further detailed investigation at a project level with mitigation.
Moderate	Significant and likely to require additional mitigation.
Minor	Not significant – may require some management to ensure the impact remains within acceptable levels.
Negligible	Not significant – no further measures required.

Table 8. A broad-scale assessment of the risk to kelp communities from the development of wave energy in Scottish waters. Evidence base relates to the current level of knowledge and certainty about the sensitivity of the receptor (kelp) and the magnitude of the impact. Magnitude is expressed at a national, regional and project scale. National significance combines receptor sensitivity and the magnitude at a national scale.

Impact	Project phase	Impact description	Summary of sensitivity to impact	Receptor sensitivity value (Table 4)	Evidence base for sensitivity	Summary of magnitude of impact (National scale)	National impact magnitude value	Regional impact magnitude value	Project site impact magnitude	Evidence base for magnitude	National overall significance of impact rating (Table 6)	Mitigation measures
Habitat loss (section 4.2)	Construction	Habitat loss describes the permanent removal of kelp habitat and/or the replacement with structures unsuitable for colonisation (e.g. mono-piles or the creation of a breakwater in the kelp zone).	As this impact results in complete and direct removal of kelp habitat, and there is no capacity to recover due to replacement structures, sensitivity is very high.	**VERY HIGH**	High	Even with the most optimistic scale of deployment of shore-based and seabed mounted devices throughout Scotland, the magnitude of this impact is likely to remain negligible relative to the abundance of kelp biotopes in Scotland. Habitat loss at the development site scale will have to be assessed on a case-by-case basis.	**NEGLIGIBLE**	**NEGLIGIBLE**	**MODERATE**	Medium	**MINOR**	Where practical it may be possible to reduce the amount of habitat loss by micro-siting a device avoiding healthy populations of kelp.
Disturbance (section 4.3.1)	Construction / Operation / Decommissioning	The partial or complete loss of biomass from kelp communities may result from a number of activities including: securing jack-up vessel, site preparation and accidental and deliberate kelp removal during operations.	After this impact, recovery of the kelp biotope to its pre-construction condition on the original substrate is highly likely. The severity of this impact will depend largely on the extent of kelp removal and the components of the biotope that are lost. Kelp communities are dynamic systems that undergo significant interannual and seasonal fluctuations in biomass and are generally resilient to temporary disturbance.	**MEDIUM**	High	Depending on the extent of kelp removal, the kelp biotope will likely recover quickly (2-5 years for kelp canopy, and >1-6 years for associated flora and fauna).	**NEGLIGIBLE**	**NEGLIGIBLE**	**MINOR**	High	**NEGLIGIBLE**	Noting that the significance of impact is considered negligible, few mitigating and management measures are proposed in addition to following best practice (see section 6).
Habitat replacement (section 4.3.2)	Operation	Activities such as: device deployment, site preparation, cable and pipe installation, mono-piling and mooring deployment will create artificial hard substrata. Materials will include: concrete, metal and secured graded rock.	After this impact, recovery of the kelp biotope to its pre-construction condition is possible. However, the replacement of natural substrata with artificial substrata may modify the outcome of succession within these novel habitats.	**MEDIUM**	Low	Where the features of the new substrata are similar to the surrounding natural rocky seabed (e.g. rock mattressing used for securing pipe work and cables) the full recovery of the kelp biotope is likely within 5-6 years. This direct impact will likely have the greatest footprint at the development site scale for shore based and seabed mounted devices.	**NEGLIGIBLE**	**NEGLIGIBLE**	**MINOR**	Medium	**MINOR**	The colonisation of artificial substrates by kelp communities can be encouraged by matching the new substrate with the natural habitat topography as closely as possible (e.g. using rock mattressing instead of polypropylene sand bags)(see section 6).

Alteration of kelp biotopes due to reduced wave energy (section 4.5)	Operation	Changes in kelp communities specialised for high-energy environments as a result of the partial or complete removal of wave energy due to energy extraction. This impact will depend on the extent and nature of energy removal. It is anticipated that where the vast majority of waves are removed regardless of their characteristics (e.g. creation of a breakwater), kelp biotopes on the landward side of renewable projects will be replaced by species specialised for lower energy environments.	Variations in water flow and altered wave action may affect canopy-forming kelp such as *L. hyperborea*, which are adapted to grow on high-energy coastlines at relatively shallow depths. A reduction in wave energy may favour other kelps such as *Saccharina latissima* and *Saccorhiza polyschides*, which prefer more sheltered environments, but support a lower diversity of associated organisms. Sensitivity is assumed to be high where projects remove high proportions of wave energy (e.g. the creation of a breakwater). However, partial removal of wave energy at shallow-water projects is likely to lead to more subtle changes in community dynamics and, in these cases, sensitivity is assumed to be low.	**HIGH / LOW**	**Medium**	Even with the most optimistic rate of development in shore-based devices throughout Scotland, the magnitude of this impact is likely to remain negligible relative to the abundance of kelp biotopes. The magnitude of impacts at a regional and site scale would depend on the nature of the energy removal. The creation of a breakwater would result in the modification of kelp biotopes on the shoreward side of the breakwater. Other wave energy technologies will extract a proportion of energy from passing waves and it remains unclear how these changes will alter affected kelp communities.	**NEGLIGIBLE**	**MINOR**	**MINOR / MODERATE (project dependent)**	**Low**	**MINOR / NEGLIGIBLE**	Good site selection will result in reduced adverse impacts on kelp communities. The reduction of wave energy is an inevitable consequence of exploiting this resource. Therefore, methods for mitigation of this impact remain difficult as a greater understanding of this type of interaction is needed.
Increased sedimentation rates (section 4.5)	Operation	The extraction of energy in addition to changes in local and regional hydromechanics may alter sediment dynamics. As a consequence, kelp biotopes may be subjected to smothering by fine sediments for long periods.	Smothering within kelp biotopes results in a reduction in light levels to sporophytes and reduced recruitment within kelp communities. Mature plants may suffer physical damage (rotting) if smothered for long time periods. Communities are tolerant to smothering over short time scales. However, long term smothering may result in the loss of this biotope altogether.	**MEDIUM**	**High**	The magnitude of this impact depends on the temporal and spatial extent of smothering in kelp biotopes. Insufficient knowledge of how different types of wave energy technologies influence local and regional sediment dynamics makes it difficult to assess the magnitude of the impact. Periodic smothering of kelp would be of lesser overall impact than long-term smothering of large areas of kelp. Consequently the overall impact magnitude is considered negligible.	**NEGLIGIBLE**	**NEGLIGIBLE**	**MODERATE**	**Low**	**NEGLIGIBLE**	Good site selection will result in reduced adverse impacts on kelp communities. For example, avoiding sites that are adjacent to extensive areas of fine sediments.
Invasive species impacts (section 4.7)	Operation	Differences in habitat characteristics on artificial structures can have considerable implications for how these novel habitats and resulting communities may encourage the propagation of non-native species. The creation of artificial substrates and the transportation of fouled vessels and infrastructure may inadvertently introduce non-native species to wave energy sites.	Some non-native species may change kelp communities, disproportionately influencing the functioning of the recipient habitats. These invasive species can produce deleterious ecological changes, displacing native species and/or altering habitat characteristics, causing severe impairment of surrounding natural communities and important ecosystem services	**MEDIUM**	**Low**	There are currently few examples of introduced species which may compete with or become established within kelp communities. The majority of non-native species exist in discrete populations, many of which are largely restricted to artificial structures.	**NEGLIGIBLE**	**MINOR**	**MODERATE**	**Low**	**NEGLIGIBLE**	Ensuring site operators follow best practice and take measures to reduce the likelihood of a species introduction (see section 6).

5.3 Discussion of risk assessment

5.3.1 Habitat loss

As habitat loss results in complete removal of kelp habitat there is no capacity to recover and sensitivity is high where this impact is predicted. The assessment of this impact is defined principally by spatial extent i.e. the extent of kelp beds directly lost by subsea structures. The magnitude of this impact is considered negligible at national and regional scales and moderate at a site-based scale. Project level magnitude will vary according to the habitat loss associated with different technologies. Where the creation of a breakwater is necessary, habitat loss will be high therefore the magnitude is considered moderate (Table 8). Selecting areas for development (during planning of projects or siting of infrastructure within the project boundary) to avoid kelp habitats would mitigate this impact, although the risk is sufficiently low at a wider scale that this may only be deemed appropriate on a project specific basis.

5.3.2 Disturbance

Disturbance (loss of kelp biomass) was identified as an impact which was present during all stages of wave energy projects (construction, operation and maintenance and decommissioning) (Table 8). The overall significance rating was considered negligible, largely due to the capacity for kelp to recover from disturbance events within 5 - 6 years, provided there is not repeated disturbance.

5.3.3 Habitat replacement

The addition of artificial structures during the construction phase will have impacts that will extend into the operation phase of wave energy projects. Colonisation of the structures is likely to follow natural patterns of succession where the artificial structures display many of the characteristics of natural hard substrata colonised by kelp and associated species. However, where artificial structures create novel habitats (e.g. metallic surfaces) that are not normally encountered, the pattern of succession is likely to be altered. Kelp habitats are therefore considered to have a medium sensitivity to habitat replacement. Magnitude is defined similarly to habitat loss (section 5.3.1) resulting in a negligible impact magnitude at a national and regional scale and a minor impact magnitude at a site level (Table 8). Material used for construction which encourages the recruitment of kelp and associated species (e.g. rock armouring) will mitigate impacts. The overall significance at a national level is considered negligible.

5.3.4 Alteration of kelp biotopes due to reduced wave energy

During the operation of wave energy arrays, kelp communities tolerant to high-energy environments may be altered under new wave regimes. Where the majority of wave energy is removed (e.g. the creation of a breakwater), evidence suggests an irreversible change in community structure is likely. Under these circumstances, receptor sensitivity is considered to be high and impact magnitude at a site scale is considered to be moderate. However, it remains unclear whether community composition will be altered where only components of wave energy are removed, as different technologies are more efficient at removing energy from specific wave lengths and heights. Kelp communities are considered to have a low sensitivity to wave energy removal from offshore moored and seabed mounted WECs and a negligible and minor impact magnitude at a national and regional/site scale respectively (Table 8). Future research in this area will better clarify the sensitivity of the receptor and magnitude of this impact. Good site selection will reduce the potential impact of wave energy extraction and the overall significance at a national level is considered negligible (see section 5.2).

5.3.5 Increased sedimentation rates

Kelp communities are considered here to have a medium sensitivity to increased sedimentation rates due to damage caused to kelp during long periods of burial and reduced recruitment of juveniles. However, the magnitude of this impact is difficult to determine as the spatial and temporal extent of smothering depends on highly variable processes. Marine renewable energy projects may result in large changes in sediment dynamics (Neill et al., 2009, Neill et al., 2012, Robins, 2012). However, it has not yet been determined how different wave energy devices alter local and regional sediment dynamics. Further research in this area would increase the confidence of these predictions. The magnitude of this impact is considered to be negligible at a national and regional scale and moderate at a site scale, principally due to the potential for changes in local sediment dynamics. Site selection based on a better understanding of how wave energy devices alter hydrodynamics and geomorphology will provide mitigation and may reduce the impact significance to negligible.

5.3.6 Invasive species impacts

Invasive species can produce deleterious ecological changes, displacing native species and/or altering habitat characteristics (see section 4.7). Therefore, the receptor sensitivity is considered to be Medium as once an introduction has taken place there is limited potential for removing the introduced species allowing recovery (Table 8). At large scales (national), non-native species richness can be positively correlated with native species richness as the extrinsic factors promoting native species richness also promote invasion (Levine et al., 2002, Sax et al., 2002). Although potentially possible, non-native species introductions are highly unlikely to cause a significant change to the national resources of kelp. Therefore, the magnitude of this impact is considered negligible at a national scale. At smaller scales, the impact magnitude is considered to be greater (minor and moderate for regional and site based scales respectively). Where site operators follow best practice and take measures to reduce the probability of introducing non-native species, the overall significance at a national level is considered to be negligible (section 5.2). Where the risk is high, monitoring at the project site may be required to identify the occurrence of non-native species. Co-ordination between strategic initiatives, research and monitoring of non-natives at a national level is needed to determine and manage the risk that introduced species pose to natural habitats and species (from this and other sectors).

6. RECOMMENDATIONS FOR BEST PRACTICE, MITIGATION AND MONITORING

6.1 Best practice

The recovery of kelp forests from possible impacts listed above and in table 8 can be facilitated by following the best practice measures outlined below:

- Careful micro-siting of devices within the kelp habitats can minimise or prevent the need for clearing of kelp and any associated disturbance.
- When new surfaces are introduced, it is recommended that they are not sterilised or treated with a biocide as this may prevent the survival of new kelp recruits. However, it is acknowledged that it may be necessary to prevent biofouling in certain circumstances.
- Where possible, refuges for fauna should be left intact. These include kelp holdfasts and small pebbles/cobbles. Refuges are especially important to fauna in large areas cleared of kelp.
- The most crucial factor in the recovery of kelp forest communities is to let the kelp canopy mature completely (> 5 years), which in turn allows the epiphyte community to become re-established. The colonisation of artificial substrates by kelp communities can be improved by matching the new substrate with the natural habitat

topography, as closely as practicable (e.g. rock mattressing as an alternative to polypropylene sand bags), and reducing scour and maintenance of the artificial substrate (Firth et al., in press).

- Avoiding sites that are adjacent to extensive areas of fine sediments would reduce the risk of smothering to kelp biotopes should there be a concern regarding localised changes in hydrodynamics and sedimentation.

Where a particular project or activity is predicted to cause a significant impact to kelp biotopes best practice measures can be employed as part of a mitigation strategy to reduce and/or avoid the impact. These measures would need to be committed to by the developer.

Best practice regarding the deployment of ballasting material (i.e. rock mattressing) includes the avoidance of placing hard substrates (e.g. rock dumping) onto areas of soft sediment because hard substrates attract different organisms to soft substrates and can facilitate the movement of non-native species around the coast (Joint Nature Conservation Committee, 2011). In rocky reef environments, rock armouring is required to reduce the likelihood of abrasion from cable movement (frond mattressing or removable concrete mattressing preferred) (Joint Nature Conservation Committee, 2011). As is generally advised, the use of cable protection should be limited to areas where it is absolutely necessary.

Other measures which may reduce disturbance to kelp habitats during cable and pipe laying include good route selection (where possible avoiding sensitive habitats and species), directional drilling, and selection of the least invasive fixing and burial techniques (OSPAR Commission, 2012, Department For Business Enterprise and Regulatory Reform, 2008). As recovery of subtidal reefs will be slower than for sand or mixed sediments the preferred option is for all cables to be buried beneath the seabed in sedimentary environments (Joint Nature Conservation Committee, 2011, Scottish Natural Heritage, 2004). During decommissioning there is a “general presumption in favour of disused installations being removed from site unless the owner demonstrates that removal of a particular component is not viable or where removal may create a net detrimental environmental impact” (The Crown Estate, 2012). Each developer must present their decommissioning plan to the regulators, where foundations and cables are buried to a safe depth, and scour protection may be left where such materials have a ‘beneficial’ environmental effect (i.e. the structure resembles the surrounding environment and is stable) (Joint Nature Conservation Committee, 2011). For example, in areas where frond mattressing was used to cover the cable, the seabed should resemble the adjacent habitat, and so should stay in place. Where necessary to remove, kelp should be removed by hand (where possible) and plants should be cut 5-10 cm above the holdfast to allow regeneration (McLaughlin et al., 2006, Wilkinson,1995).

Best practice to reduce the impact of non-native species involves taking action to prevent their introduction or to limit further spread (Scottish Government, 2012, Cook et al., 2014, Payne et al., 2014). Marine users (of all sectors) are encouraged to produce biosecurity plans which detail steps taken to reduce the chance of introducing potentially damaging non-native species (see Payne et al. (2014) for guidance).

In trying to reduce project impacts, it is also necessary to consider factors which have been applied to address engineering issues. For example, the recovery of kelp communities following installation of artificial structures and materials is compromised where features of the artificial habitats (e.g. surface roughness and orientation) depart from the characteristics commonly found in naturally-occurring rocky habitats. Where antifouling coatings are used, these are designed to minimise the development of communities on their surfaces and therefore a balance between the operational risks of fouling and the opportunity to support community re-growth is appropriate.

6.2 Monitoring

Monitoring may be required to detect whether mitigation measures taken have been effective and whether impacts have occurred. This will be agreed at a project-level between the developer, the regulator and nature conservation advisers and should be designed based on the predictions made during the preparation of an application for consent. It is important to consider and define the spatial and temporal extent of any monitoring employed along with specific objectives on what changes are anticipated and how these will be measured. Before-After Control-Impact (BACI) approaches are typically used to test if a change has occurred in a community (Underwood, 1994, Smith, 2002). Kelp forests are characterised by a high level of interannual and seasonal variability (Walker and Richardson, 1955, Walker, 1956, Dayton et al., 1992) therefore careful consideration must be given to the design of monitoring programs to detect impacts, for example, the amount of sampling effort required to detect a given change.

Many authors have highlighted the common failings in the experimental design of BACI monitoring programs and readers are encouraged to explore opportunities for improvement, where possible (Underwood, 1992, Underwood, 1994, Stewart-Oaten and Bence, 2001, Smith, 2002,). Common failings include not assigning adequate reference locations (controls) to determine spatial variance within the characteristic being sampled, failing to sample enough time periods or times within periods to determine the temporal variance within the characteristic being sampled and sampling the same area many times so that samples may no-longer be treated as independent. Statistical methods should be employed during the design of the monitoring strategy to determine appropriate survey effort to attain the required confidence in results (detection of changes attributable to the development). As monitoring effort also needs to be proportional to the risk, a compromise between the quantity of resources needed to detect a change and the perceived consequence of that impact should be made (section 6.3).

Many of the impacts expected from the creation of wave energy projects are long term impacts changing slowly over time. Such impacts are likely to have greater spatial variability than temporal variability. For such impacts, experimental design should focus on sampling more control areas to determine spatial variability. It may also be necessary to conduct a pilot study to understand the spatial and temporal variability of the characteristic being sampled to ensure effect-size (i.e. number of replicate samples needed to detect a given change) are defined for the development of monitoring programs. Characteristics to be sampled in a pilot study may include, but are not limited to, density and height of kelp and biodiversity and abundance of selected components of the biotope such as epiphytes, holdfast fauna, urchins and juvenile fish. Such sampling could be considered during the design of characterisation surveys to support the EIA process to improve the baseline against which monitoring results would be compared.

6.3 Framework for assessing the significance of impacts of wave energy projects on kelp biotopes – project level assessment

The definition of significance is critical to drawing conclusions on identified impacts. There is ambiguity around how significance is defined in impact assessment and it is defined differently whether as a critical element of conservation legislation (such as Likely Significant Effect in HRA) or in EIA practices. This section describes an approach to determining the level of significance of impacts in relation to kelp communities.

For wave energy project developers, the primary concern during preparation of a consent application is to gather adequate information regarding any significant impacts. Due to the challenges in undertaking quantitative assessments, determining whether an impact is ‘significant’ is, to some extent, a value judgement made on a case-by-case basis. It depends on whether an impact permanently affects the natural heritage (at a local, regional or national level), either by destroying an important feature of the natural heritage present on a specific site, or by causing extensive changes to the natural heritage over a wide area. The risk assessment used here (see section 5.2) addresses both these considerations by attempting to assess both the receptor sensitivity and the magnitude of the impact. For project developers, an assessment of the impacts on kelp communities must be made with reference to the overall conservation objective. Section 2.4 defines Favourable Conservation Status which must be maintained for kelp habitats listed as Annex I habitats under the Habitats Directive.

The following decision-tree could be used as a basic framework to support assessment of the significance of the impact on kelp biotopes resulting from activities associated with future wave energy projects during construction, operation, maintenance and decommissioning, taking into account the location and scale of the project (Figure 8).

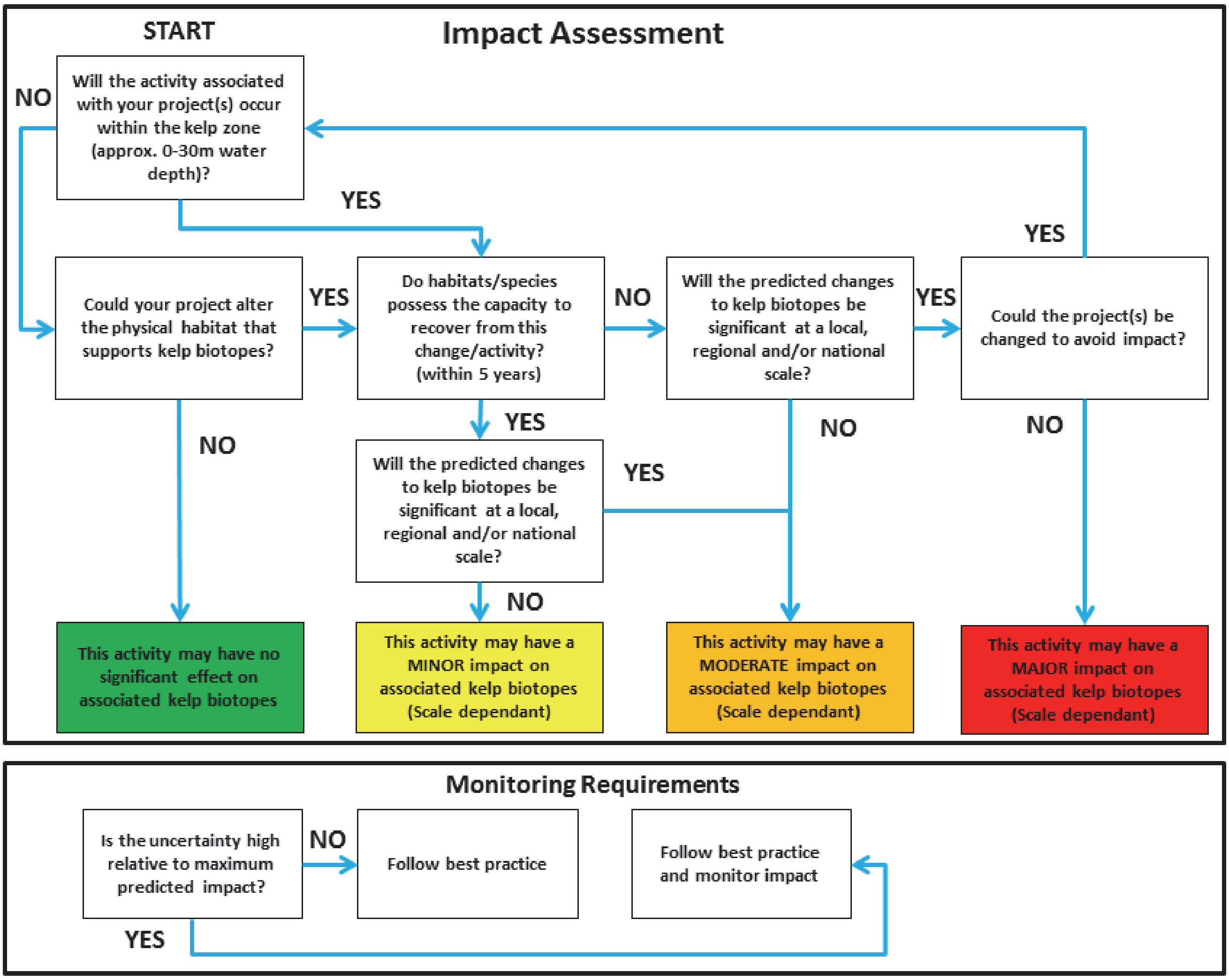

Figure 8. A decision-tree to provide a framework for assessing the impact of wave energy projects on kelp biotopes.

Figure 8 shows the process by which impacts to kelp communities may be assessed on a project-by-project basis. An activity that will deploy infrastructure within kelp habitats or alter the physical habitat (e.g. changes in local hydrodynamics and/or sediment dynamics) in a nearby kelp habitat must assess the temporal and spatial extent of this change. Where recovery is likely within a 5 year period, (e.g. a one-off disturbance event) kelp communities can be regarded as being able to recover from that activity. To determine whether a particular impact is ‘significant’ the assessor must assign value to the kelp resource being affected. This is best achieved by determining the scale at which this resource is important (Institute of Ecology and Environmental Management, 2010). For example, some kelp habitats can be considered important at a regional scale due the scarcity of kelp in other areas and the services that the resource provides to other habitats and/or species within that region. This stage in the assessment process requires the assessor to consider the type of impact expected along with the conservation and management objectives of the area. Where significant impacts are predicted to occur, the developer should consider design options to reduce the impact during the EIA process.

Monitoring to assess the extent of a particular impact is needed where there is uncertainty about the sensitivity of the receptor or magnitude of the impact and to improve EIA practices. Monitoring effort should be proportionate to the risk of impact identified, in line with the guiding principles of the EIA process (European Commission, 2013). Best practice guides exist for both monitoring and for undertaking activities with the least environmental impact (section 6.1 and 6.2). For example, determining the significance of changes in sediment dynamics, for which there remains a large degree of uncertainty, may require a modified approach. For this the reader is referred to Best Practice Guides such as that produced for modelling coastal processes for offshore wind farm projects (Lambkin et al., 2009).

7. CONCLUSIONS

Kelp biotopes are important drivers of coastal biodiversity and are amongst the most productive ecosystems on earth. Therefore, it is important to investigate the capacity for activities associated with the future exploitation of wave energy resources in Scotland to alter kelp biotopes and their functioning. This report summarises current approaches to exploiting wave energy and reviews best available knowledge to establish the significance of such impacts. This review explores the likelihood that this novel industry will undermine national and international conservation objectives and provides wave energy developers, consultants and other interested parties with guidance to reduce impacts on these important communities.

Kelp habitats in Scotland are much more extensive than the most optimistic plans for wave energy exploitation. Recent models developed to predict the abundance of kelp throughout Scotland estimate that current lease areas are likely to overlap with 1.2% of Scotland’s typical kelp resource (3600 km^2) where kelp has a 50% likelihood of being rare or more abundant. Development areas themselves are likely to occupy only a small proportion of each lease area, reducing extent of overlap further, therefore the impacts to kelp habitat per installation of WEC are expected to be relatively small compared to the natural perturbations that kelp habitats experience on a whole-ecosystem scale. At the scale of individual sites, some changes can be expected and these effects are considered throughout this report. Kelp maintains a high resilience to human disturbance due to the capacity for species to regenerate and re-colonise. Although different features of the kelp community require varying lengths of time to recover, most kelp biotopes will largely return to a natural condition within a 5-year period, assuming no further disturbance takes place. There remains a degree of uncertainty regarding indirect effects of energy extraction, non-native species introductions and changes to sediment dynamics. Future research in these areas will better address these concerns. Site developers are encouraged to follow best practice where possible and focus monitoring efforts where there is genuine concern of a likely significant effect.

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ANNEX 1: BIOTOPE COMPLEXES FOUND WITHIN HIGH ENERGY INFRALITTORAL ROCK HABITATS WITH KELP (IR.HIR.KFAR)

Biotope	Description	Habitat	Similar Biotopes	Protection
Ala	*Alaria esculenta on exposed sublittoral fringe bedrock*	Sublittoral fringe (lower shore), on bedrock and very large boulders, 0-5m depth, extremely exposed	-	Annex I (EC habitats directive)
Ala.Myt	*Alaria esculenta, Mytilus edulis* and coralline crusts on very exposed sublittoral fringe bedrock	Sublittoral fringe (lower shore), occurs on bedrock, 0-5m depth, very exposed	IR.HIR.KFaR.Ala.Ldig (occurs on less exposed shores)	-
Ala.Ldig	*Alaria esculenta* and *Laminaria digitata* on exposed sublittoral fringe bedrock	Sublittoral fringe (lower shore), on bedrock and/or vertical and very steep rock, 0-5m depth, very exposed - moderately exposed	IR.HIR.KFaR.Ala.Myt (*L. digitata* is absent and the diversity of red seaweeds are lower	-
LhypFa	*Laminaria hyperborea* forest with a faunal cushion (sponges and polyclinids) and foliose red seaweeds on very exposed upper infralittoral rock	Upper infralittoral, on bedrock and massive boulders, 0-20m depth, extremely exposed to exposed	IR.HIR.KFaR.LhypR.Ft (Less conspicuous encrusting fauna than in LhypFa). IR.MIR.KR.Lhyp.Pk (lacks the dense faunal turf of LhypFa)	Annex I (EC habitats directive)
LhypR	*Laminaria hyperborea* with dense foliose red seaweeds on exposed infralittoral rock	Infralittoral, on bedrock and massive boulders, 0-30m depth, extremely exposed to exposed	-	Annex I (EC habitats directive)
LhypR.Ft	*Laminaria hyperborea* forest with dense foliose red seaweeds on exposed upper infralittoral rock	Infralittoral, on bedrock and large boulders, 0-20m depth, extremely exposed to exposed, occurs beneath a zone of *Alaria esculenta* and above a *L. hyperborea* park (LhypR.Pk)	IR.HIR.KFaR.LhypFa (occurs in areas with more wave-surge. The cushion fauna in this biotope is markedly more abundant than kelp forests in areas with less wave surge)	-
LhypR.Pk	*Laminaria hyperborea* park with dense foliose red seaweeds on exposed lower infralittoral rock	Infralittoral, on bedrock and large boulders, 10-50m depth, very exposed to exposed, occurs below the exposed kelp forests (LhypFa and LhypR.Ft) where wave surge is reduced	-	-
LhypR.Loch	Mixed *Laminaria hyperborea* and *Laminaria ochroleuca* forest on exposed infralittoral rock	Infralittoral, on bedrock and boulders, 5-20m depth, very exposed to exposed, commonly occurs below exposed kelp forests (LhypR.Ft)	-	-
IR.HIR.KFaR.LsacSac	*Laminaria saccharina* and/or *Saccorhiza polyschides* on exposed infralittoral rock	Infralittoral, on scoured bedrock and mobile substrate	-	Annex I (EC habitats directive)

ANNEX 2: BIOTOPE COMPLEXES FOUND WITHIN HIGH ENERGY SEDIMENT-AFFECTED OR DISTURBED KELP COMMUNITIES (IR.HIR.KSED)

Biotope	Description	Habitat	Similar Biotopes	Protection
Sac	*Saccorhiza polyschides* and other opportunistic kelps on disturbed sublittoral fringe rock. Occurs in disturbed areas (by storms or sand scour)	Very exposed - moderately exposed, on boulders, sublittoral fringe (lower shore), upper- Infralittoral , 0-5 m	IR.HIR.KFaR.LsacSac (occurs in deeper water, supports a slightly richer faunal community of species)	-
LsacSac	*Laminaria saccharina* and/or *Saccorhiza polyschides* on exposed infralittoral rock	Very exposed - moderately exposed, on boulders or cobbles, Infralittoral , 0-30 m	-	-
LsacChoR	*Laminaria saccharina, Chorda filum* and dense red seaweeds on shallow unstable infralittoral boulders or cobbles	Moderately exposed, occurs on boulders, cobbles, pebbles and gravel in the upper-infralittoral, 0-5m depth	IR.HIR.KSed.XKHal, IR.HIR.KSed.EphR, IR.MIR.KT.XKTX	-
DesFilR	*Dense Desmarestia spp.* with filamentous red seaweeds on exposed infralittoral cobbles, pebbles and bedrock	Exposed, occurs on boulders and bedrock in the upper-infralittoral, 5-10m depth	IR.HIR.KFaR.Sac IR.HIR.KFaR.LsacSac IR.FIR.SG.CC.Mo	-
XKScrR	Mixed kelps with scour-tolerant and opportunistic foliose red seaweeds on scoured or sand-covered infralittoral rock	Exposed – moderately exposed, occurs on bedrock and boulders in the infralittoral zone 0-20m depth in close proximity to sand	IR.HIR.KSed.XKHal	-
ProtAhn	*Polyides rotundus, Ahnfeltia plicata and Chondrus crispus* on sand-covered infralittoral rock	Exposed – moderately exposed, occurs on bedrock, cobbles and pebbles with mobile sands in the infralittoral zone, on sand-covered rock, depth 5-10m	IR.HIR.KSed.XKHal	-

ANNEX 3: AN OVERVIEW OF POSSIBLE WAVE ENERGY PROJECTS CURRENTLY IN DEVELOPMENT (WITH AGREEMENT FOR LEASE STATUS)

Location	Development	Capacity	Developer / Owner	Placement*	Leased area	Area currently developed	Possible Project Development Plan*	Reference
Pentland Firth and Orkney Waters	Brough Head	200MW	Aquamarine Power Ltd	nearshore	3 km of coastline	-	Phase 1a: up to 10 Oyster devices (10 MW) Phase 1b: up to 40 Oyster devices (40 MW)	Xodus Group (2011)
	Costa Head	200MW	Scottish & Southern Energy	offshore	24 km^2	-	Phase 1: 4 AWS-III units (10 MW) Phase 2: up to 76 AWS-III units (190 MW)	Xodus Group (2012)
	Farr Point	50MW	Pelamis Wave Power Ltd	offshore	100 km^2	3 km^2	Phase 1: 10 Pelamis machines (10 MW) Phase 2: up to 10 Pelamis machines (10 MW)	Aquatera (2011)
	Marwick Head	50MW	Scottish Power Renewables	offshore	-	7.78 km^2	Phase 1: 12 Pelamis machines (9 MW) Phase 2: 54 Pelamis machines (49.5 MW)	Scottish Power Renewables (2012)
	West Orkney Middle South	50MW	Not known	offshore	30 km^2	-	Phase 1: up to 20 Pelamis machines (10 MW) Phase 2: up to 50 MW of Pelamis machines	RSK Environment Ltd. (2012)
	West Orkney South	50MW	Not known	offshore	30 km^2	-	Phase 1: up to 20 Pelamis machines (10 MW) Phase 2: up to 50 MW of Pelamis machines	RSK Environment Ltd. (2012)
Other Areas	South West Shetland	10MW	Aegir Wave Power Ltd / Pelamis Wave Power Ltd. and Vattenfall AB	offshore	10 km^2	-	Up to 14 Pelamis machines (10 MW)	Xodus Group (2011)
	Galson, Isle of Lewis	10MW	Lewis Wave Power Ltd / Aquamarine Power Ltd	-	-	-	-	-
	Bernera, Isle of Lewis	10MW	Pelamis Wave Power Ltd.	offshore	100 km^2	2 km^2	14 Pelamis machines (10 MW)	http://www.pelamiswave.com/our-projects/project/4/Bernera-Wave-Farm
	North West Lewis (South)	30MW	Lewis Wave Power Ltd / Aquamarine Power Ltd.	nearshore	-	~3 km^2	40-50 Oyster devices (40 MW)	Royal Haskoning (2012)
	Burghead, Moray Firth	Sea trials only	Pelamis Wave Power Ltd	Two sites	-	-	Non-commercial device demonstration and sea trials only	-

*nearshore – within 3 km of the coast, offshore – 3-15 km from the coast ** These details are not definitive due to the change in ownership of the project

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ISBN: 978-1-78391-181-3

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